CHAPTER 1

ENVIRONMENTAL SATELLITES

INTRODUCTION

Satellite images, or pictorial representations of satellite-sensed information, are some of the most frequently used tools in the fields of meteorology and oceanography.

As a Navy or Marine Corps observer, one of your primary duties will be to acquire satellite imagery. You may also be required to process the imagery to better display features of interest to the analyst. Later, as you begin to analyze meteorological and oceanographic situations, you will use satellite imagery as one of your most important sources of information.

In this chapter, we begin with an explanation of some of the basic terminology used to describe satellite orbits and satellite tracking. Next, we introduce environmental satellite programs, and then describe the various types of environmental satellites and explain their purposes. We then discuss some of the most common types of satellite imagery, and acquaint you with a few basic imagery enhancement techniques. We complete the chapter by taking a brief look at some of the equipment and methods that you will use to acquire and process satellite imagery.

SATELLITE TERMINOLOGY

LEARNING OBJECTIVES: Define basic terminology used in relation to satellite orbits and satellite tracking.

Before you can effectively acquire and use satellite imagery, it is important that you become familiar with some basic satellite terminology.

Environmental satellites orbit the earth at various altitudes. Some environmental satellites operate lower than 800 kilometers (500 statute miles), while others operate as high as 35,800 kilometers (22,300 statute miles). To stay in orbit, lower altitude satellites must orbit faster than higher altitude satellites. As a result, satellites in orbit at 800 kilometers complete an orbit in a little over 100 minutes, while satellites in orbit at 35,800 kilometers require 24 hours to complete an orbit.

The inclination angle of a satellite's orbit is the angle the satellite's path makes as the satellite crosses the equator (fig. l-1). This term is usually referred to as the satellite *inclination.*

Satellites that have an inclination of 0 degrees circle the earth over the equator in an *equatorial orbit.* When a satellite in an equatorial orbit moves from west to east in the same direction that the earth rotates, its speed and altitude may be adjusted so that it is always located in a stable orbit over the same position on the equator. Satellites in these orbits are called *geostationary, earth-synchronous,* or *geosynchronous* since they are stationary relative to their position over the equator. Their fixed location provides continuous coverage of the same area over a 24-hour period.

As shown in figure 1-1, satellites with high orbital angles generally cross over the polar regions and are called polar-orbiting *satellites.* These satellites orbit the earth about 14 times a day and provide global coverage every 12 hours. A single orbit of a polar-orbiting satellite is composed of an *ascending node,* which is the period of time when the satellite is traveling from south toward the north, and a *descending node,* which is the period of time when the satellite is traveling from north toward the south.

The position directly under a satellite on the surface of the earth is called the satellite *subpoint* or *nadir,* while the track of the satellite subpoint along the surface of the earth is called the *satellite path.*

Now let's consider some additional terms used in satellite orbits and satellite tracking.

Because the earth rotates, each time a polar orbiting satellite crosses the equator, its position is further west than its position on the previous orbit. This change in position is called the *nodal increment* (fig. l-2). The total time it takes the satellite to complete an orbit is called the *nodal period.* The term *epoch* refers to a specific reference point in a satellite's orbit.

Most polar-orbiting environmental satellites use a nodal increment and a nodal period that keep pace with the rotation of the earth and keep the satellite path crossing the equator at the same local mean time

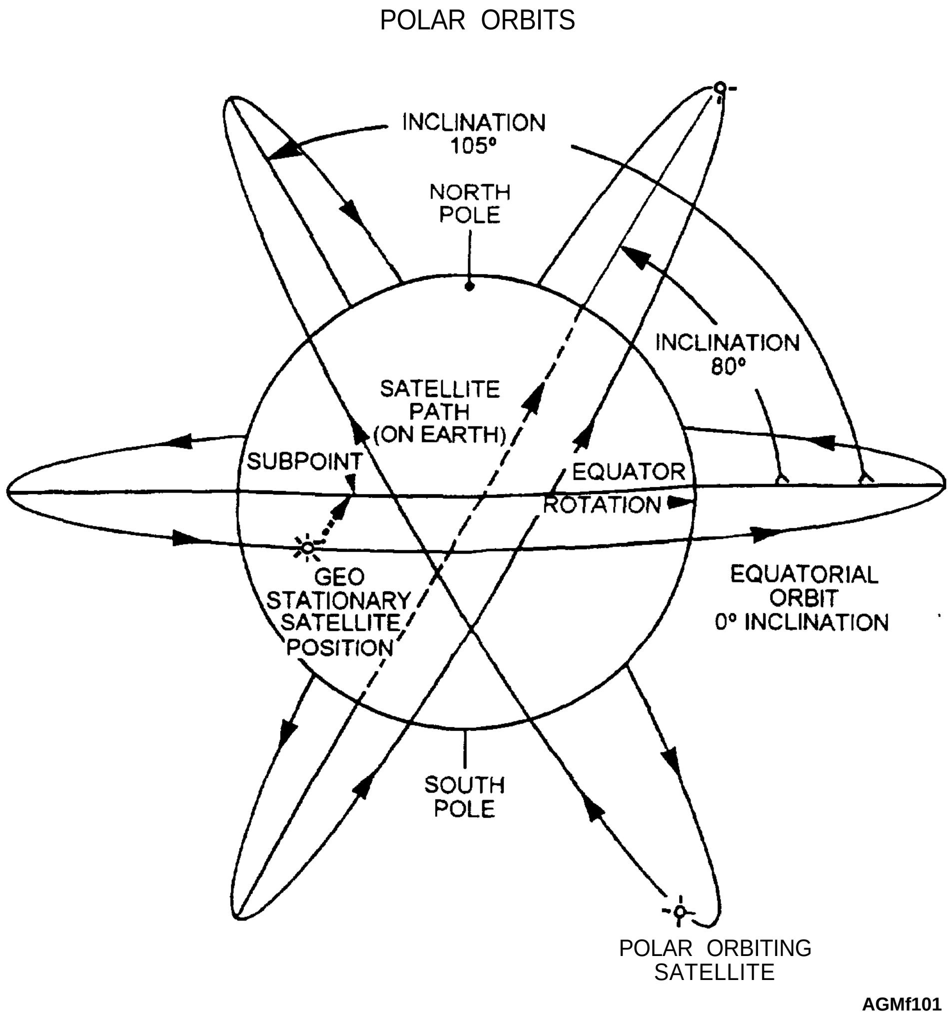


Figure 1-1.—Satellite inclination.

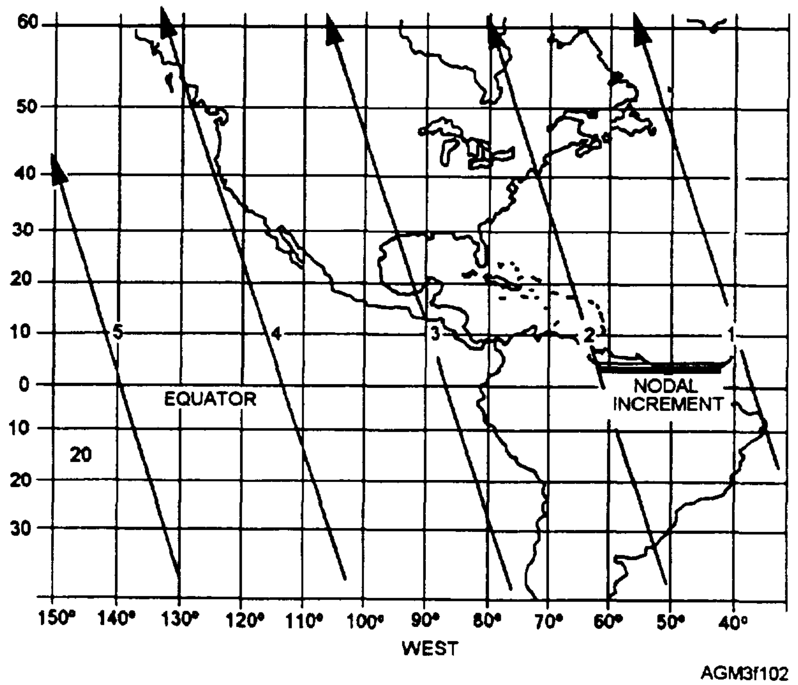


Figure 1-2.—Nodal increment–the westward change in position of a polar-orbiting satellite's path on earth on successive orbits.

(LMT) during each orbit. These types of orbits are called *sun-synchronous orbits*—they are synchronized with the movement of the sun across the earth's surface. For instance, an orbit may be calculated so that the satellite path crosses the equator on the descending node 2 hours after sunrise on each orbit.

The ascending and descending nodes may additionally be identified by the relative time of day, such as day-ascending, day-descending, night-ascending or night-descending node (fig. l-3). When an ascending node crosses the equator at a particular relative time, the descending node of the same orbit will cross the opposite side of the earth at a LMT about 12 hours opposite the ascending node LMT (plus one-half the nodal period). For example, if a satellite has a sun-synchronous orbit with a day-ascending node, then the descending node on the other side of the earth will be a night-descending node. To simplify the situation, only the relative time of day of the **ascending node** is referenced. For example, an environmental satellite known as a day-ascending satellite will always be over the sunlight portion of the earth when moving north, and it will always be over the dark side of the earth when traveling south. Night-ascending satellites will move northward over the dark side of the earth and southward over the sunlight side of the earth.

The National Oceanic and Atmospheric Administration (NOAA) normally maintains at least two operational polar-orbiting satellites. One is in a sun-synchronous morning orbit and the other is in a sun-synchronous afternoon orbit. Thus, each satellite provides two images every 24 hours (one day image and one night image), producing a total of four images a day over any given area.

When a satellite achieves orbit around the earth, the orbit is rarely a perfect circle. Most orbits are actually elliptical and they change over time because the earth is not a perfect sphere; it flattens over the poles and bulges near the equator. The gravitational pull of the earth, sun, and moon also plays a role. When the satellite comes closest to the earth, the satellite is said to be at *perigee,* and when it is farthest away from the earth, the satellite is said to be *apogee.* When at

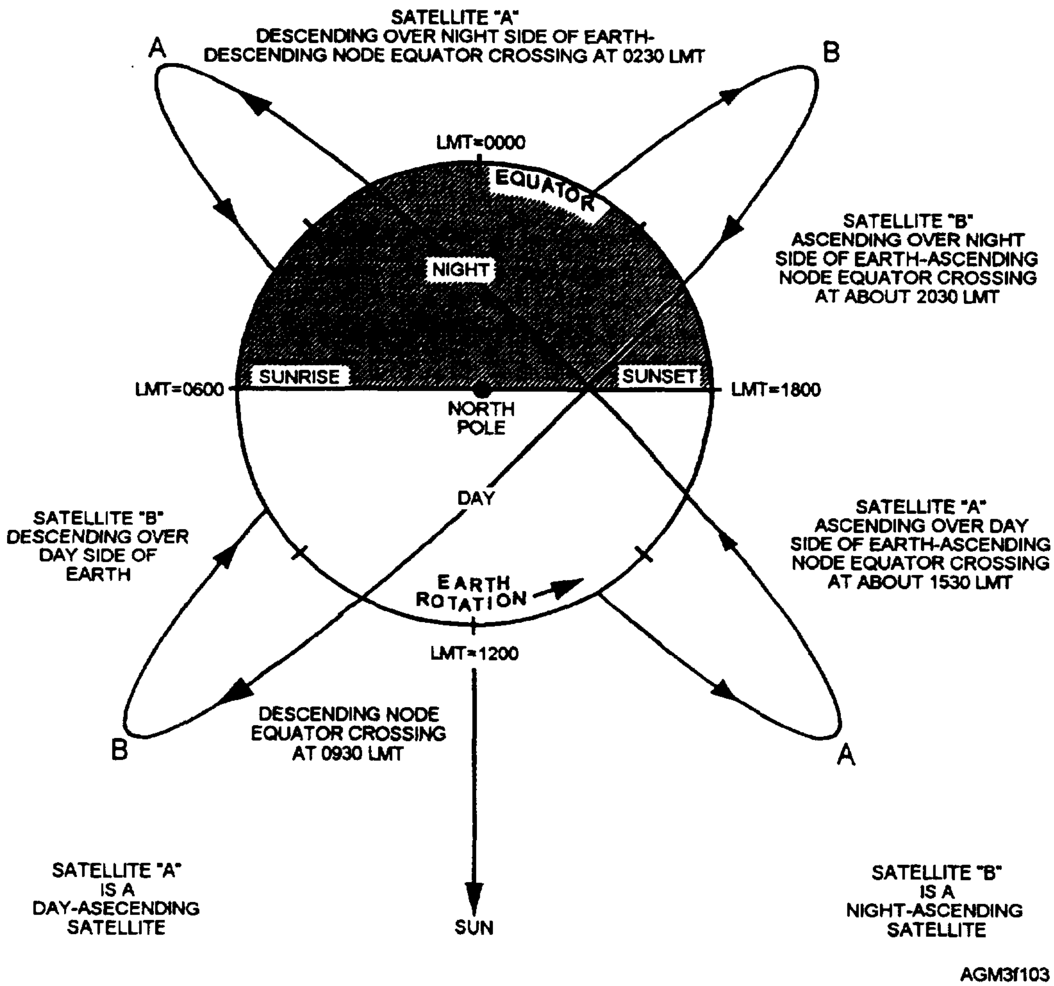


Figure 1-3.—Day-ascending and night-ascending polar orbits.

perigee, satellites move faster. When at apogee, satellites travel slower. This change in velocity complicates tracking of polar-orbiting satellites. For convenience and ease of orbit calculations, time is referenced to zero when a polar-orbiting satellite passes the equator northbound, and increases through a complete orbital period. Figure 1-4 illustrates the changes that can occur in the perigee and apogee of a satellite over time.

Most polar-orbiting satellites also have *anomalies* in their orbits. An anomaly in an orbit is any change or deviation from a perfectly stable orbit. Some anomalies are planned into an orbit so that the orbit will remain sun synchronous as earth revolves around the sun during the course of a year. Anomalies further complicate satellite orbital predictions.

REVIEW QUESTIONS

Q1. A satellite with an equatorial orbit would have an inclination angle of how many degrees?

Q2. What term is used for a satellite with an equatorial orbit moving with the same speed and direction as the earth?

Q3. What term is used to describe the period of time when a polar orbiting satellite is traveling south to north?

Q4. What is meant by the term "sun-synchronous" satellite?

Q5. If a satellite has an ascending node time of 1400 local, what would be the approximate descending node time at the same location?

Q6. What are the major factors that would cause changes in a satellites apogee and/or perigee position?

TYPES OF ENVIRONMENTAL SATELLITES

LEARNING OBJECTIVES: Recognize the various functions performed by environmental satellites. Identify the major satellite programs operated in the United States. Identify specific types of geostationary satellites, polar-orbiting satellites, DMSP satellites, and foreign satellites. Recognize the advantages and disadvantages of geostationary and polar-orbiting satellites.

The first meteorological satellite was launched in April of 1960, and was known as TIROS-1 (Television and InfraRed Observation Satellite). Since that time, numerous satellites with more advanced technology have been introduced, and today there are many different designs of meteorological and oceanographic satellites. Most of these satellites have a variety of sensor packages that survey electromagnetic energy at several different wavelengths.

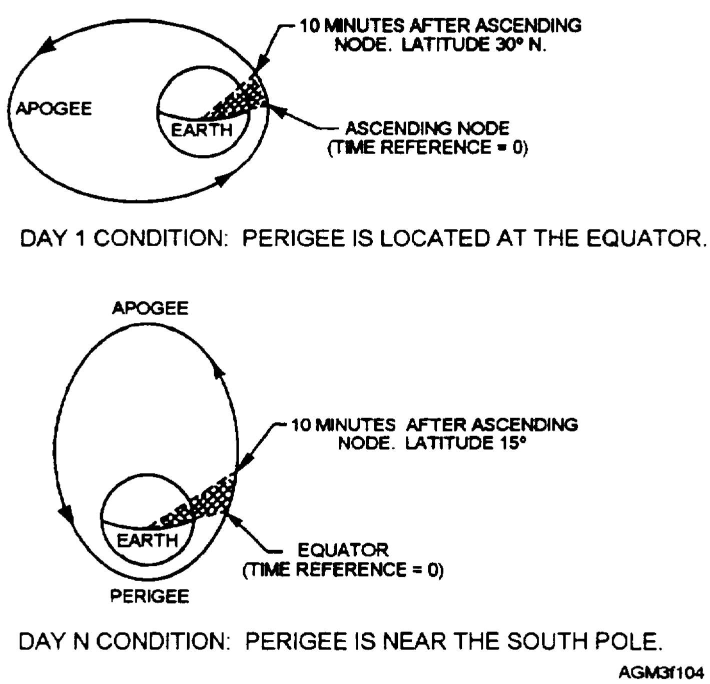


Figure 1-4.—Typical elliptical satellite orbit and changes in the orbital shape over a period of time.

Besides collecting imagery, most environmental satellites perform additional functions. Some satellites contain communications packages designed to receive and relay signals between earth stations and other satellites and to collect and relay observation reports from automatic observation sites or buoys. Some satellites carry search and rescue (SAR) beacon locators. More advanced satellites carry sophisticated instruments known as "atmospheric sounders." These systems use infrared and microwave energy to provide vertical temperature and moisture profiles of earth's atmosphere from the surface up to 30 miles. They also evaluate atmospheric stability. In addition, satellites can be used to measure a variety of other environmental parameters, such as sea surface temperature, wave height, snow/ice cover, low-level wind speed and direction, and ozone distribution. Although these functions are very important to meteorology and oceanography, you will not normally be involved in this type of data collection or data processing. In this module, we discuss only the differences in satellites that are important to you in acquiring satellite imagery.

In the United States, both the U.S. Department of Commerce and the U.S. Department of Defense operate meteorological satellite programs. The National Oceanic and Atmospheric Administration (NOAA), a division under the Department of Commerce, operates its satellite programs through the National Environmental Satellite, Data, and Information Service (NESDIS). Their primary meteorological satellite programs are the Geostationary Operational Environmental Satellite (GOES), and the Advanced Television InfraRed Observation Satellite-NOAA (ATN) polar-orbiter (also called a TIROS-N or NOAA satellite). Both systems are energized with solar power while in orbit. The Department of Defense oversees the Defense Meteorological Satellite Program, usually referred to as the DMSP.

GEOSTATIONARY SATELLITES

Geostationary satellites are placed at an altitude (35,800 km) where their orbital period exactly matches the rotation of the earth. The satellite sensors scan the earth in horizontal lines, starting near the North Pole and working down towards the South Pole. Geostationary satellites are ideal for making large-scale, frequent observations of a fixed geographical area centered on the equator. Thus, they are better suited to track rapidly moving large-scale disturbances in the atmosphere, or to look closely at small-scale or short-duration changes in the atmosphere. However, their distance from the earth limits the resolution of the imagery. In addition, these satellites do not "see" the poles at all, and to achieve global coverage of just the equatorial regions, a network of 5 to 6 geostationary satellites is required. Figure 1-5 shows atypical GOES satellite.

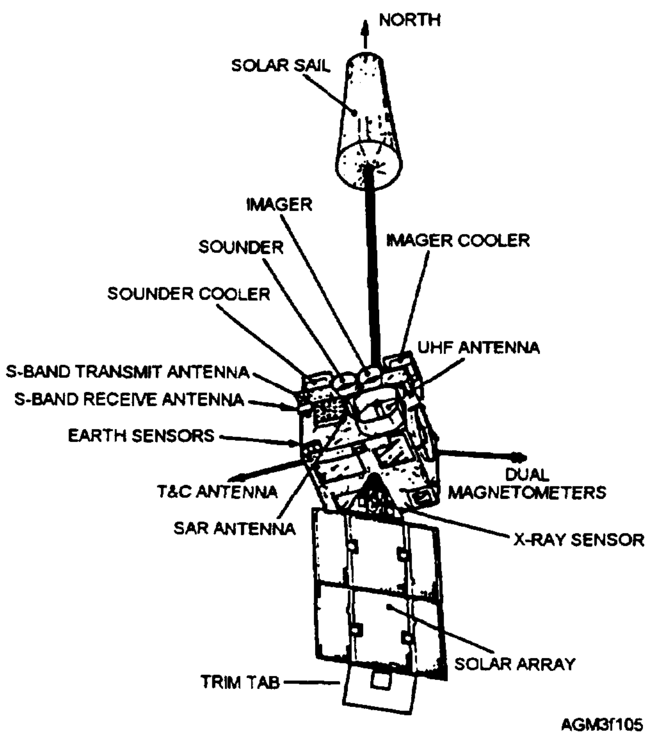


Figure 1-5.—GOES satellite.

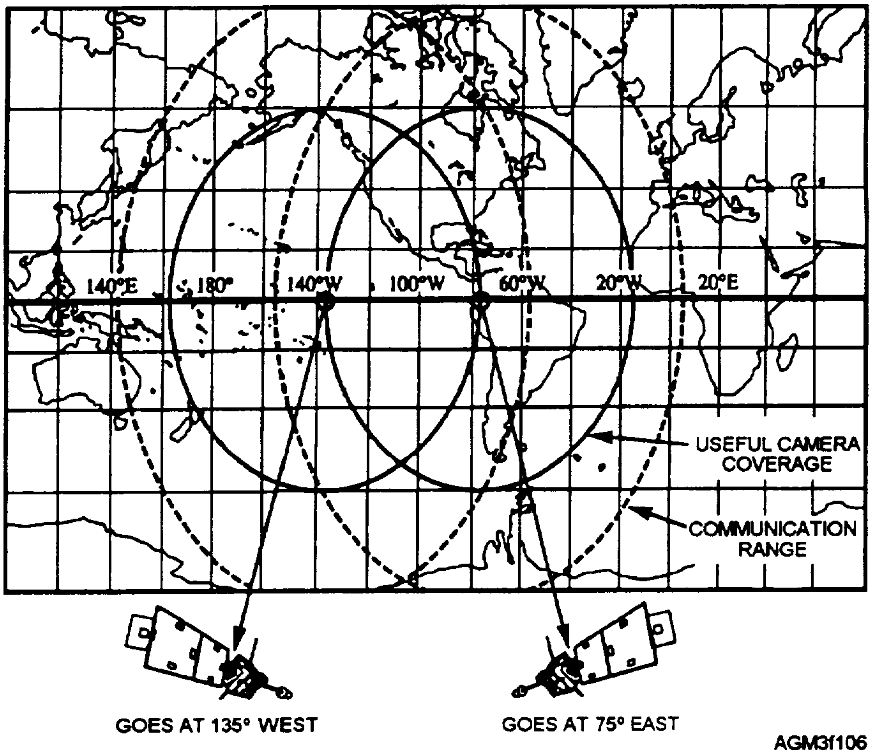


Figure 1-6.—Data coverage of GOES East and GOES West satellites.

NOAA operates two geostationary satellites known as GOES East and GOES West. The GOES East satellite (currently GOES-8), is located over 75° west longitude while GOES West (currently GOES-9) is located over 135° west longitude. Figure 1-6 shows the area of the earth covered by GOES East and GOES West.

POLAR ORBITING SATELLITES

Polar orbiting satellites closely parallel the earth's longitude lines. They pass over the vicinity of the North and South Poles with each revolution. As the earth rotates to the east beneath the satellite, each pass monitors an area to the west of the previous pass. Since

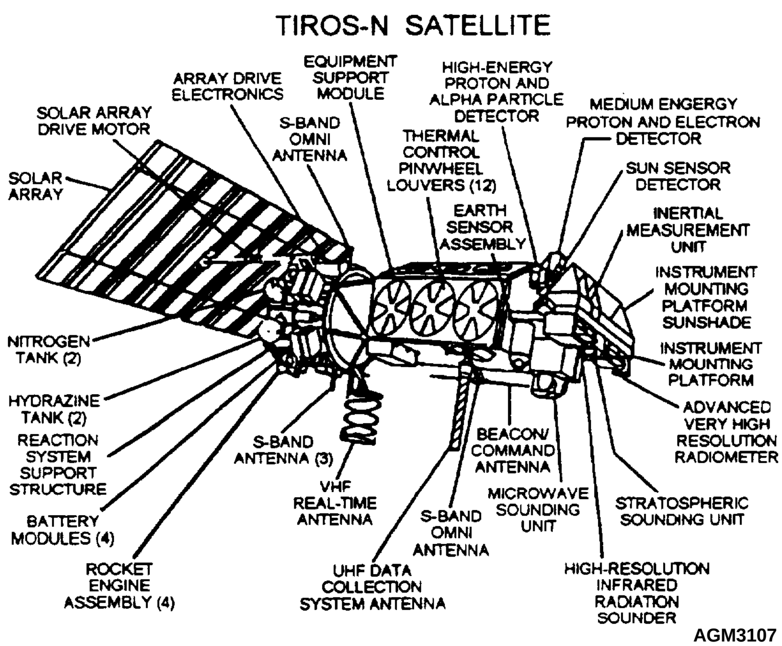


Figure 1-7.—Advanced TIROS-N satellite.

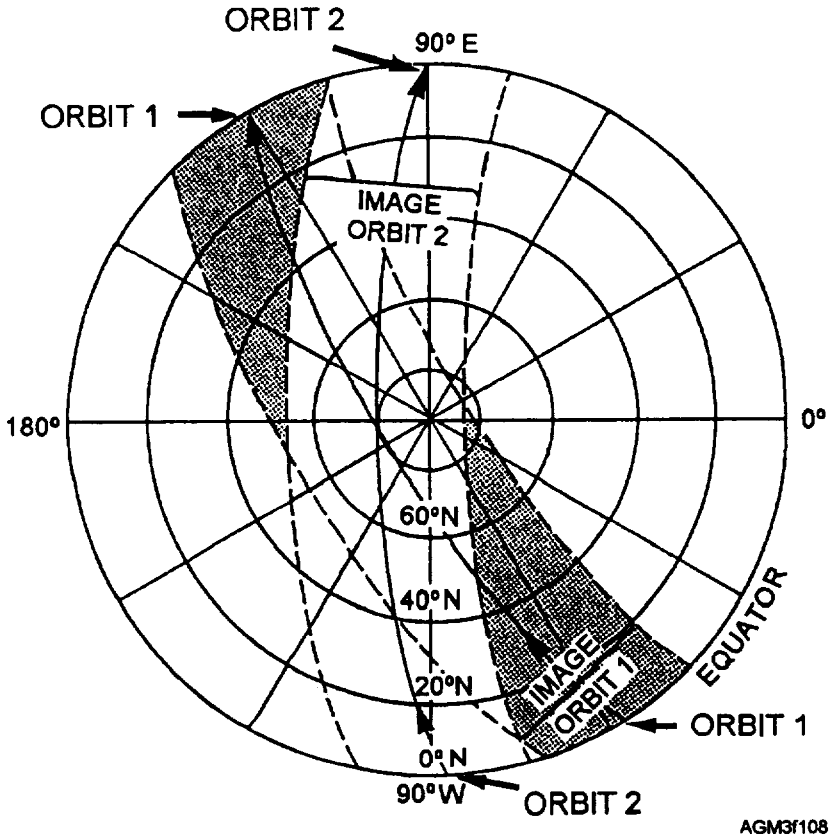


Figure 1-8.—Data coverage on successive orbits of a polar-orbiting satellite.

polar-orbiting satellites circle the earth at a much lower altitude (about 850 km), they have the advantage of photographing clouds directly beneath them at relatively high resolution. Although nearly every environmental satellite provides both infrared and visual imagery, polar-orbiting satellites are better suited to gathering imagery from the high-latitude and polar regions. They also provide imagery as they cross the equatorial regions. This makes them extremely well suited for oceanographic applications where slow changes in water temperature are adequately tracked by only two or four images a day.

The width of the usable image from a polar-orbiting satellite is a function of the satellite's altitude. The average swath width is about 2700 km (1500 nmi). Polar-orbiting environmental satellite orbits are planned so that the usable image area overlaps slightly. Figure 1-7 shows a typical TIROS-N satellite, while figure 1-8 shows the area covered by usable imagery on successive orbits of a polar-orbiting satellite.

As of this writing, NOAA 12 (TIROS-ND) and NOAA 14 (TIROS-NJ) are the two fully operational polar-orbiting satellites in the TIROS-N series. A new series of polar-orbiting satellites will be launched by the spring of 1998, and will be referred to as NOAA-POES (NOAA-Polar-orbiting Operational Environmental Satellite). Table 1-1 compares various characteristics between geostationary and polar-orbiting satellites.

Table 1-1.—Geostationary Versus Polar-orbiting Characteristics

Characteristic	Geostationary	Polar Orbiting
1. Image frequency	15 minutes	12 hours
2. Resolution at high latitudes	Poor	Good
3. Areal coverage	Full disk	2,700 km wide strip
4. Gridding	Automatic	At receiving station
5. Data acquisition system cost	Very expensive	Inexpensive
6. Average life expectancy	5-6 years	3-4 years

DMSP SATELLITES

DMSP satellites are polar-orbiting satellites managed by the Department of Defense that provide very high-resolution imagery. These satellites can provide real-time worldwide support to operating forces for both shipboard and selected shore sites. Near real-time (stored) environmental imagery can also be provided by the Fleet Numerical Meteorology and Oceanography Command (FNMOC) at Monterey, California. Because imagery from DMSP satellites is encrypted for transmission, special processing equipment is required for download.

Each direct transmission received from DMSP contains two channels, visible and infrared. The channels are transmitted so that one channel will provide "fine" data (0.56 km resolution) and the other will provide "smooth" data (2.7 km resolution). Unique sensors aboard DMSP satellites allow for the collection of visual imagery at night by using lunar illumination. The determination of channel assignment is made by the Air Force Weather Agency located at Offutt AFB, Nebraska.

DMSP satellites also have a special passive microwave sensor known as a SSM/I (Special Sensor Microwave/Imager). The SSM/I measures thermal energy emitted and reflected by the earth's surface and atmosphere by using the microwave portion of the electromagnetic spectrum. SSM/I data is particularly useful in water vapor and sea ice analysis. In addition, wind speeds over ocean areas can be estimated by evaluating the brightness temperatures of the white caps of the waves. DMSP satellites are launched as "F" series satellites (F-12, F-13, etc.).

A few satellites are equipped with a high-frequency radar device known as a *scatterometer.* A scatterometer measures reflected microwave signals from ocean waves. This data is then used to estimate low-level wind speed and direction over data sparse ocean areas. Scatterometry data is available from FNMOC.

FOREIGN SATELLITES

Several other countries also support active meteorological satellite programs. China operates a geostationary satellite called the *Fengyun.* Russia has *Meteor* polar-orbiting satellites and *GOMS* geostationary satellites in service. They also support a joint project with India that has a geostationary satellite—the *INSAT,* in place over the Indian Ocean. Japan supports a geostationary satellite called the GMS over the western Pacific Ocean. In Western Europe, several nations jointly support the European Space Agency (ESA). ESA maintains a geostationary meteorological satellite called *METEOSAT* in place over the Mediterranean region. Figure 1-9 shows the global-scale monitoring program of the World Weather Watch Global Observation System.

New satellites are routinely placed in orbit to replace older satellites as they wear out and fail. Each new satellite usually incorporates new technology and may provide slightly higher image resolution or an entirely new type of sensor. As you read this, the satellites just mentioned may be out of service and replaced by newer models.

Information concerning the operational status of all environmental satellites is available via the Internet at the *NOAASIS* world wide web site operated by NOAA/NESDIS. This site provides updated position data for geostationary satellites as well as tracking information bulletins for polar-orbiting satellites. The

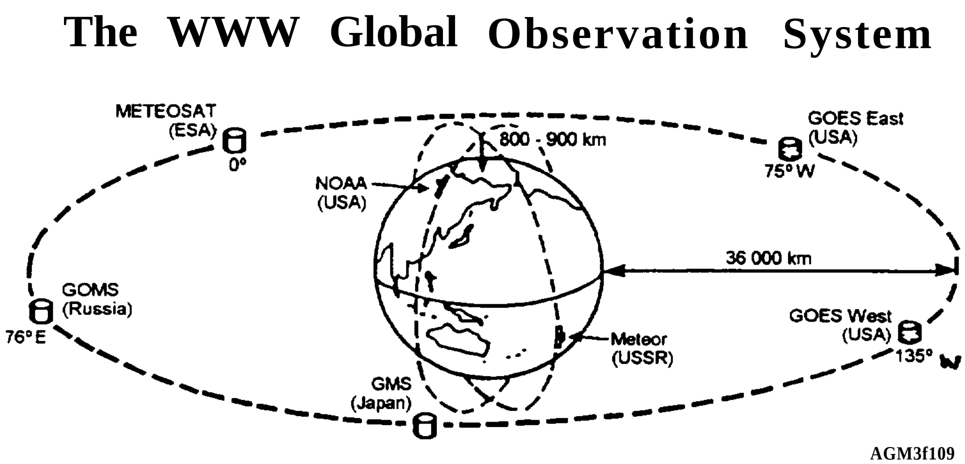


Figure 1-9.—The World Weather Watch Global Observation System.

site also contains transmission schedules and transmitting frequencies for various United States and foreign-operated satellites.

REVIEW QUESTIONS

Q7. *What is the purpose of a satellite atmospheric sounder?*

Q8. *What is the main advantage of geostationary satellites?*

Q9. *Which GOES satellite provides imagery over all of South America?*

Q10. *What type of satellite is the NOAA 14?*

Q11. *What are the main advantages of polar-orbiting satellites?*

Q12. *What is the average swath width of a polar-orbiting satellite?*

Q13. *Which organization is responsible for providing near real-time DMSP environmental imagery to the fleet?*

Q14. *Which geostationary satellite will provide imagery for Spain and Portugal?*

SATELLITE IMAGERY

LEARNING OBJECTIVES: Recognize the particular advantages of imagery from geostationary satellites and polar-orbiting satellites. Define spatial resolution, radiometer, electromagnetic wave, and albedo. Define the terms *visual, infrared, near infrared,* and *water vapor* as they relate to satellite imagery. Recognize the advantages of visual, infrared, and water vapor imagery.

The pictures or images available from environmental satellites vary, depending on the type of satellite and the type of sensor in use. Geostationary satellites continuously "look" at the same geographical area of the earth. However, the image area is centered on the satellite subpoint on the equator. At the subpoint, clouds are seen from directly overhead. Further away from the subpoint, clouds seen in the image are viewed from an angle, and feature distortion occurs. Cloud cover is often overestimated toward image edges because the sensor is actually viewing the clouds from the side. Near the horizon, the image is considered unusable due to distortion.

Polar-orbiting satellites are in much lower orbits than geostationary satellites; therefore, the satellite can only see a limited portion of the earth as the satellite sensors scan from horizon to horizon. Because of the acute view angle near the horizon, the satellite image near the horizon is usually of little value and is usually not processed or displayed by receiver station equipment.

IMAGERY RESOLUTION

Satellite sensors designed to produce pictures or images of earth, its oceans, and its atmosphere are very different from the cameras used to take a photograph. They are more like a video camera, only much more specialized. These scanning sensors are called *radiometers*, and instead of film, an electronic circuit sensitive only to a small range of electromagnetic wavelengths measures the amount of energy that is received. Satellites may can-y several different image sensors, each of which is sensitive to only a small band of energy at a specific wavelength. The radiometer used by the TIROS-N and POES series satellites is known as the Advanced Very High Resolution Radiometer (AVHRR) and contains many types of sensors.

Satellite sensors scan across the surface of the earth in consecutive *scan lines* along a path normal to the direction of travel of the satellite. As the sensor moves through a scan line, it very rapidly measures energy levels for only a very small portion of the earth at a time. Each individual energy measurement will compose a single picture element or *pixel* of the overall satellite image. The sensor then assigns an intensity level from 0 to 256 for each pixel. The size of the area (field-of-view) scanned by the sensor determines the *spatial resolution* of the overall image. Thus, the **smaller** the area scanned for each pixel, the **higher** the spatial resolution. Some sensors may scan an area as small as 0.5 km across (high resolution), while others scan areas as large as 16 km (low resolution). When composed into an image, smaller pixels allow the image to be much clearer and show greater detail. Clouds and land boundaries appear better defined. If objects are smaller than the sensor resolution, the sensor averages the brightness or temperature of the object with the background. Normally, the sensors aboard satellites are able to provide better resolution for visual imagery than for infrared imagery. DMSP satellites have very high-resolution capabilities in both visual and infrared.

TYPES OF IMAGERY

All things (with a temperature above absolute zero) emit radiation in the form of electromagnetic waves. The wavelengths emitted by each object depend primarily on the object's temperature. Higher temperatures cause electrons to vibrate faster and therefore produce shorter wavelengths. The sun emits radiation at several different wavelengths, and the range of these wavelengths is known as the *electromagnetic spectrum* (fig. 1-10, view A). Electromagnetic wavelengths in the visual and infrared region are usually measured in *micrometers.* A micrometer is equal to one-millionth of a meter and is represented by the symbol µm. Micrometers are also referred to as microns.

The sun emits a maximum amount of radiation at wavelengths near 0.5 µm. The earth, which is obviously much cooler, emits most of its radiation at longer wavelengths of between 4 and 25 µm. For this reason, the earths radiation is referred to as *long-wave radiation* and the sun's energy is referred to as *shortwave radiation.* The atmosphere is a strong absorber of radiation at certain wavelengths and is relatively transparent to others. Generally, the atmosphere is transparent to wavelengths associated with incoming solar radiation; but because of the presence of water vapor, carbon dioxide, and other elements, the atmosphere is largely opaque to the outgoing terrestrial wavelengths.

When data signals from a satellite sensor scan are compiled at the satellite receiver on earth, the pixels and scan lines form an image. The image composed of measurements of energy in the visual range forms a *visual image.* The data from sensors that measure energy in the infrared band compose an *infrared image.*

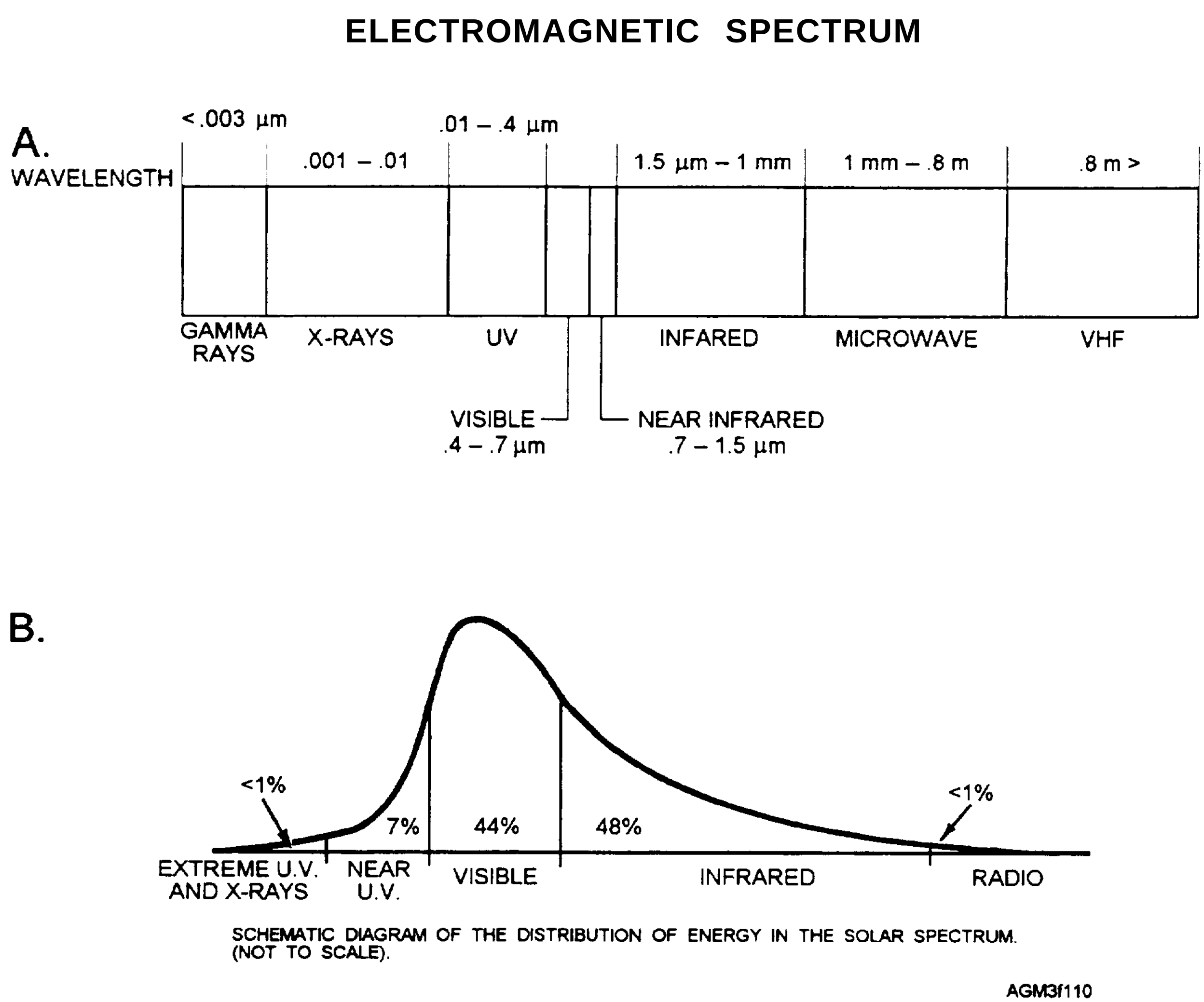


Figure 1-10.—(A) The electromagnetic spectrum, and (B) the distribution of solar energy incident to the earth.

Visual Imagery

The electromagnetic energy that your eyes can see, *visible light*, ranges from a wavelength of .7 µm for red light, through the visible spectrum (red, orange, yellow, green, blue, indigo and violet) to .4 µm for violet light. Figure 1-10, view B, shows the distribution of the various wavelengths of solar energy incident on the earth's atmosphere. About 44 percent of the sun's energy falls on the earth in the form of light. Although some light is absorbed, much of the light incident on the earth's atmosphere and surface is reflected back into space.

The reflected light from the earth is measured by a sensor aboard the satellite that is sensitive only to electromagnetic energy in the visual range. The sensor measures the energy seen in each pixel and assigns it a reading from 0 for no energy sensed to 256 for very high energy sensed. Measurements are transmitted to the earth, and the consecutive pixels and scan lines are processed to compose an image.

The more direct sunlight reaching objects, the brighter they will appear. The amount of reflectivity of an object is termed *albedo,* and is dependent on the object's surface texture and color. In visual-range images, areas of low reflected light (low albedo), such as water and forest regions, appear black. Areas of high reflected light (high albedo), such as snow, appear white (fig. 1-11). Cloud tops reflect a lot of light, so they are usually very light shades. Space surrounding earth reflects no light, so it appears black.

Visible imagery is very useful in both atmospheric and oceanographic analysis because reflectivity varies considerably among atmospheric, land, and oceanic features. An obvious disadvantage of visible imagery is that it is only available during daylight hours.

Infrared Imagery

Look again at figure 1-10, view B. You can see that most of the sun's energy that falls on the earth is in the infrared band. Most of the shorter wavelengths of infrared energy are reflected from the earth much the

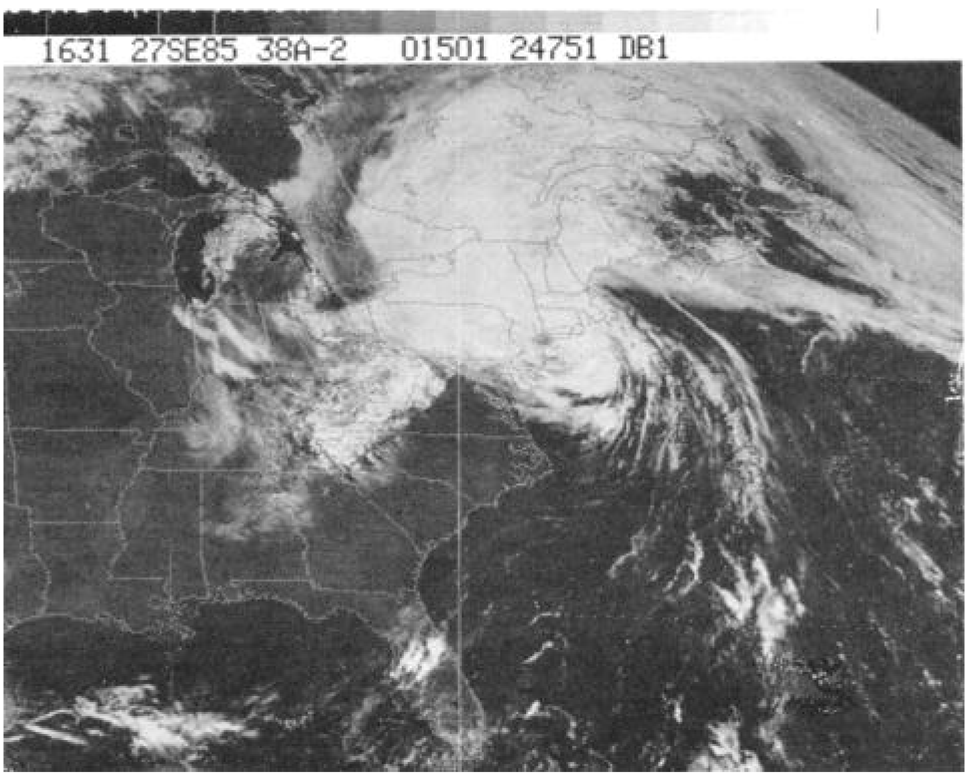


Figure 1-11.—GOES visual (VIS) image. Space and low reflective areas appear black, while high reflective areas, such as cloud tops, appear white.

same as visible light (longer wavelength infrared energy is absorbed). Satellites normally carry sensors that measure energy levels in several specific bands of infrared wavelengths, and the radiation measured is directly related to the temperature of the different radiating surfaces. Since all surfaces radiate some amount of thermal (heat) energy, a major advantage of infrared satellite imagery is that it is available even when the earth is dark. Energy levels are measured much the same way that visual-range energy is measured. The individual measurements from each pixel, when composed into an image of the earth, form an *infrared image.*

Most infrared satellite imagery is measured at wavelengths of 10.2 µm to 12.8 µm (far infrared). Some satellites are able to augment visual and far infrared imagery by also measuring near infrared (NIR) wavelengths (.74 µm to 2.0 µm). NIR imagery generally shows better land/water contrast and simplifies low-level feature identification, such as shorelines, snow/ice, and vegetation.

The satellite receiver and processor control how the composed image will look. Normally, the energy measurements for infrared image pixels are assigned g-ray shades with low-energy readings appearing white and high-energy readings appearing black. The lighter the gray shade, the colder the object seen. With IR images, space surrounding the earth is white, and warm land or water masses are dark gray or black.

Infrared imagery is an excellent tool for oceanographic analysis, such as evaluating sea surface temperatures and determining ocean front and eddy locations. It is also very helpful for identifying high clouds and upper-level wind flow, but less reliable for identifying low-level features. Look at figure 1-12. Notice how lower level clouds, very distinct in the visual image, are more difficult to determine in the

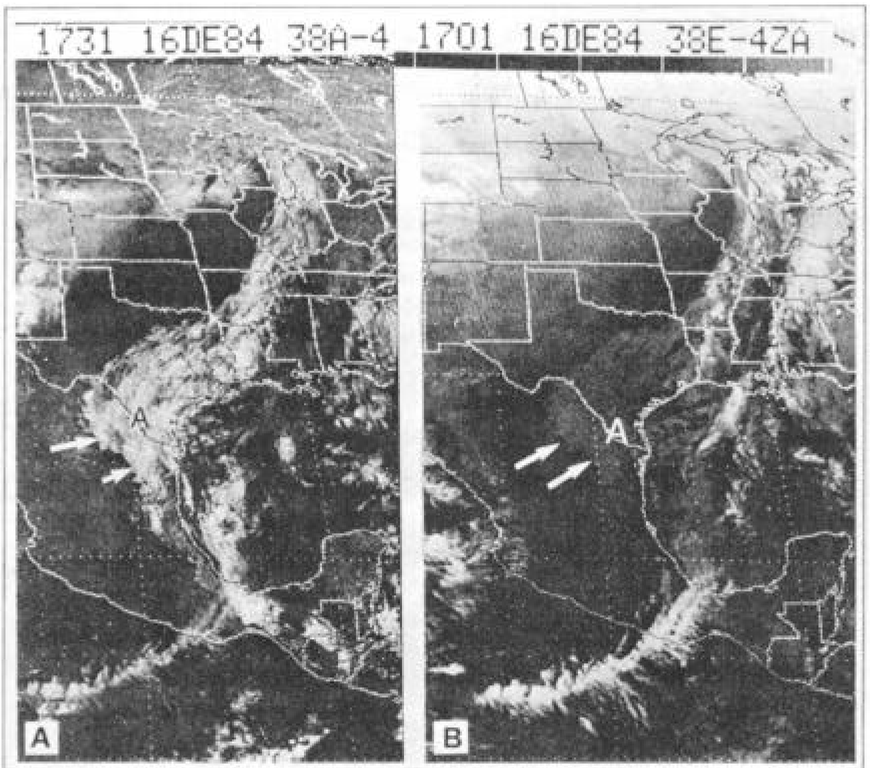


Figure 1-12.—GOES visual image on left compared to GOES infrared (IR) image on right. Space and cold cloud tops appear white and warm water and land areas appear dark gray to black in an IR image.

infrared image when surface temperatures and cloud top temperatures are relatively the same.

Water Vapor Imagery

Concentrations of water vapor in the atmosphere absorb essentially all 6.7 µm radiation coming from below. Thus, one of the infrared sensors carried aboard the GOES and the METEOSAT measures radiation at this wavelength. When the energy measurements from this type of sensor are composed into an image, the result, shown in figure 1-13, is called a water-vapor channel or *WV* image. Areas of high water-vapor content (high humidity) appear in the lighter gray shades while lower humidity areas appear darker.

The main advantage of the water vapor channel is better definition of the moisture distribution in the upper atmosphere. If moisture is present in the upper levels, we associate this with upward vertical motion. Conversely, upper-level dryness is a good indication

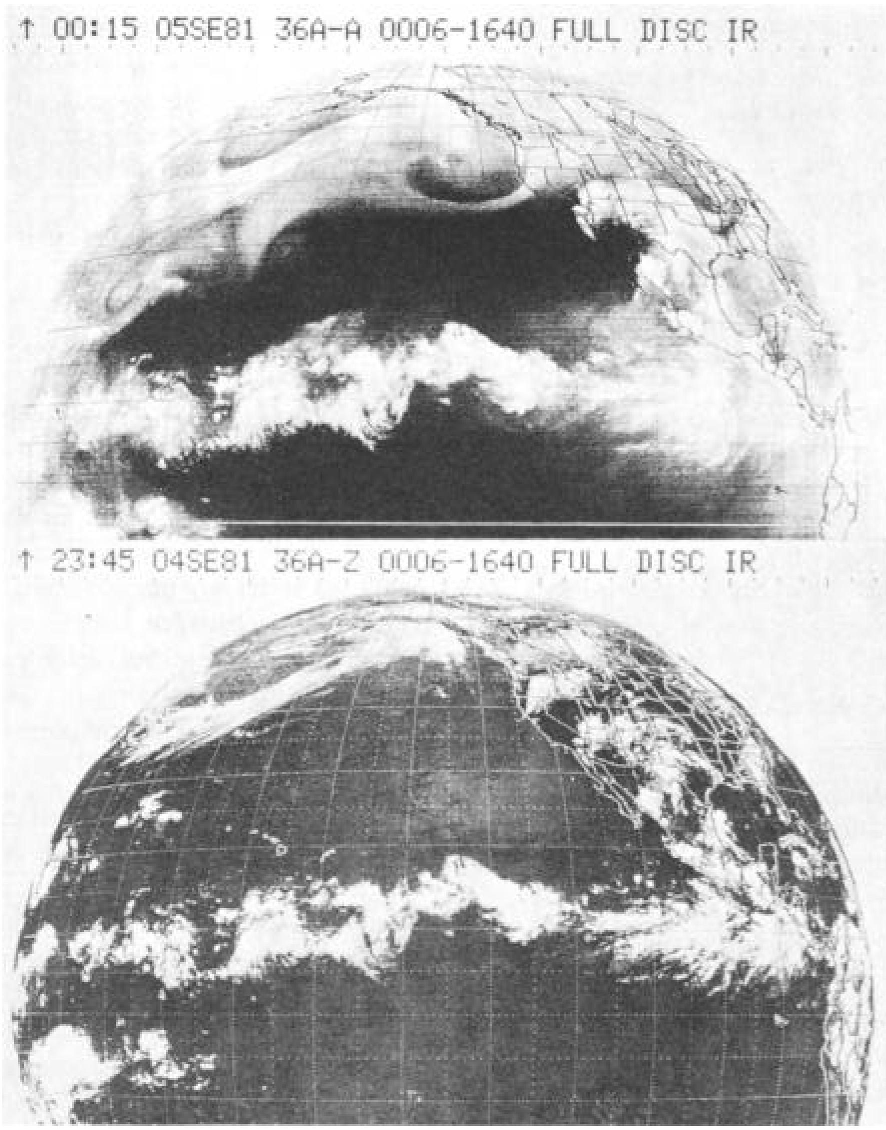


Figure 1-13.—GOES full disk (hemisphere) infrared water-vapor (WV) channel image (top) and full disk visual (VIS) image (bottom) at the same time. The WV image shows a better depiction of the extent of the system than the VIS image.

of downward vertical motion. Water vapor imagery can detect these motions without clouds present. Circulation patterns in the upper atmosphere, including the jet stream, are easily identified using WV imagery.

REVIEW QUESTIONS

Q15. What is the image-scanning sensor of a satellite called?

Q16. Which sensor would provide higher resolution data, one with a spatial resolution of 1 kilometer or one with a spatial resolution of 4 kilometers?

Q17. *Consider two objects, one cold the other hot. Which object is emitting electromagnetic energy at relatively longer wavelengths?*

Q18. *The majority of the radiation emitted by the earth is known by what term?*

Q19. *In the visible spectrum, what color has the longest wavelength?*

Q20. *Of the following objects, sand or grass, which one would have a higher albedo?*

Q21. *What are the major advantages of infrared imagery?*

Q22. *How do relatively cold objects appear on IR imagery?*

Q23. *How do high humidity areas appear on water vapor images?*

Q24. *What are the advantages of water vapor imagery?*

IMAGERY ENHANCEMENT

LEARNING OBJECTIVES: Identify various types of user-defined and predefined satellite enhancement curves. Identify information contained in the GOES legend and temperature scale.

Most satellite data processors have the capability to assign colors or various gray shades to specific JR imagery energy readings. When an image is produced by using either color or an alternating gray shade rather than the straight black-to-white or white-to-black shading, the color or gray shade assignment is called an *enhancement.* An enhanced satellite image allows the user to see specific details of an image with better definition. Infrared imagery is often enhanced to better define a small range of critical temperatures.

TYPES OF ENHANCEMENT CURVES

Unenhanced imagery displays a linear transition of gray shades from black (warm) to white (cold). It is a steady increase in brightness that produces little contrast. Enhanced imagery displays a transition of mostly non-linear gray shades. The result is an improved contrast of various key temperatures that makes specific temperature assessment much easier. There are two methods of enhancing satellite imagery: brilliance inversions and thresholding (curves). Brilliance inversion enhancements use a range of gray shades (or color) to identify a range of specific temperatures. With threshold enhancements, a single gray shade is used to identify a whole range of temperatures. In other words, all the temperatures in a particular range have the same gray contour. Figure 1-14 shows enhanced infrared images.

User-Defined Enhancement Curves

When possible, enhancement curves should be locally developed and evaluated. Most satellite receiving equipment used by the Navy, such as the AN/SMQ-11, allow for the creation of custom designed enhancement curves. Keep in mind that when you are developing enhancement curves, you should limit the number of features to be enhanced. You must allow for enough detail as possible without making the display too confusing. There are always compromises between simple enhancement curves, which sacrifice detail but can quickly be interpreted in an operational environment, and complex curves, which maximize information content but require more time to interpret.

Figure 1-15 is a graphic illustration of a basic enhancement curve table. Count values as input would be plotted on the horizontal axis, and modified count values for the final display would be plotted on the vertical axis. These count values range from 0 to 255, where 0 appears as black and 255 appears as white. Values in between produce varying shades of gray. By adding, deleting, and positioning points within the graph, an input color or gray shade is mapped to an output color or gray shade. As points of reference, six count values on the horizontal axis correspond to the six sets of temperatures at the bottom of the graph. Count values on the vertical axis result in the gray shade range as referenced at the right of the graph. The

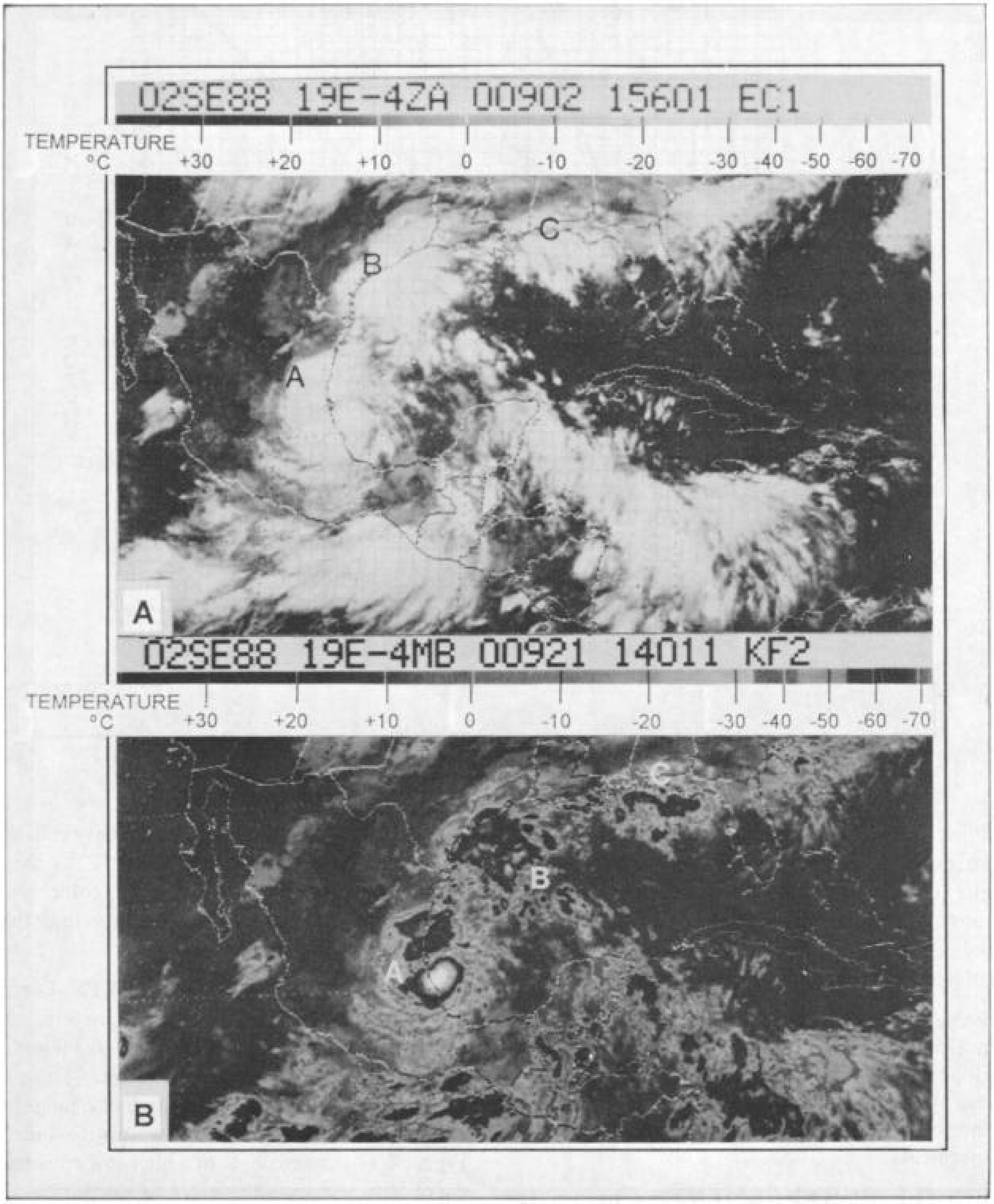


Figure 1-14.—Processed GOES infrared images with temperatures added to gray-shade scale. (A) A predefined "ZA" enhancement (straight black to white shading) and (B) a predefined "MB" enhancement used to better define cloud-top temperatures (cloud height) in thunderstorms at points A, B, and C.

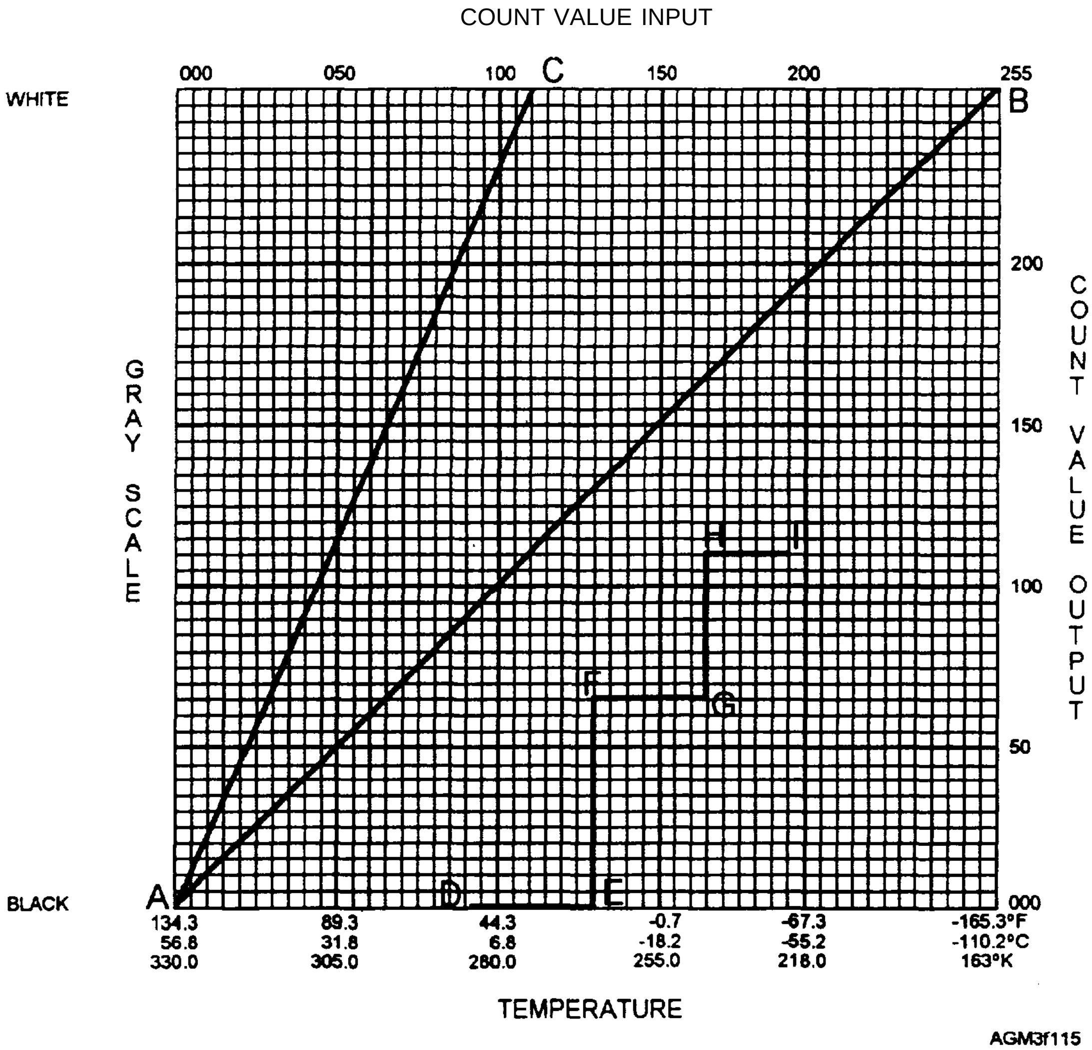


Figure 1-15.—Illustration of a basic enhancement curve table.

solid line (AB) represents a case of no enhancement. As an example, if you acquired an image and the warmer (darker) end of the spectrum required greater definition, the data could be modified as illustrated by the segment (AC). In this case, all the gray shades from +56.0°C to 5.8°C would be displayed.

Enhancement curves for high-resolution imagery from DMSP and NOAA satellites are usually developed based upon three basic configurations, depending on desired results. They are the single enhancement, the high-low enhancement, and the split enhancement.

SINGLE ENHANCEMENT.—The single enhancement curve is defined over a complete count value range, but for either a default or specified temperature range. This curve will give you all gray shades across your defined temperature range. For example, if you were interested in only low clouds or sea surface temperatures, you might only enhance the image in a range from +20°C to -10°C, as shown in figure 1-16. Any areas on the image colder than the lower limit will appear white. Areas warmer than the upper limit will appear black.

HIGH-LOW ENHANCEMENT.—For high-low enhancement curves, two ranges are selected. For each of these, a unique part of the gray-shade and count value scale is applied to each range. Thus, warm temperatures may be in the gray-black range, while cold temperatures may be in the white off-white range. Figure 1-17 is an example of a high-low enhancement curve with temperature ranges of +30°C to +05°, and -20°C to -40°C. Areas colder than the lowest minimum temperature will appear white. Areas warmer than the highest maximum temperature will appear black. Areas which are temperatures between the upper and lower ranges will appear black.

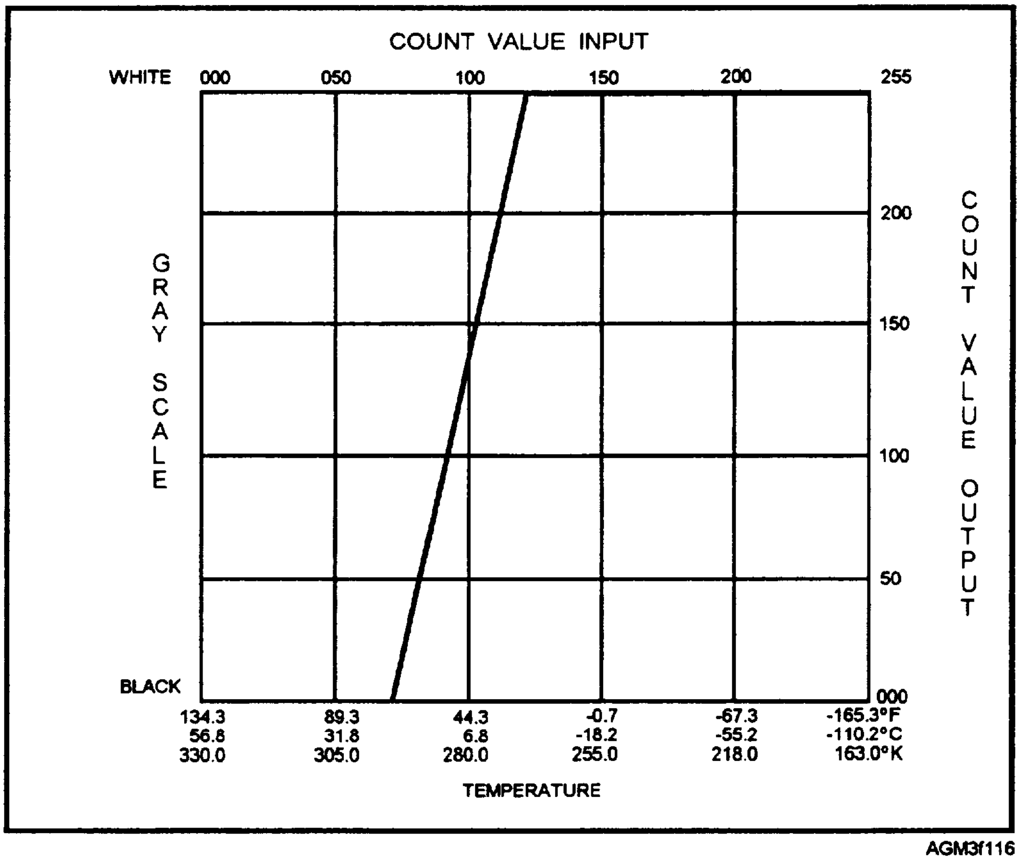


Figure 1-16.—Single enhancement curve.

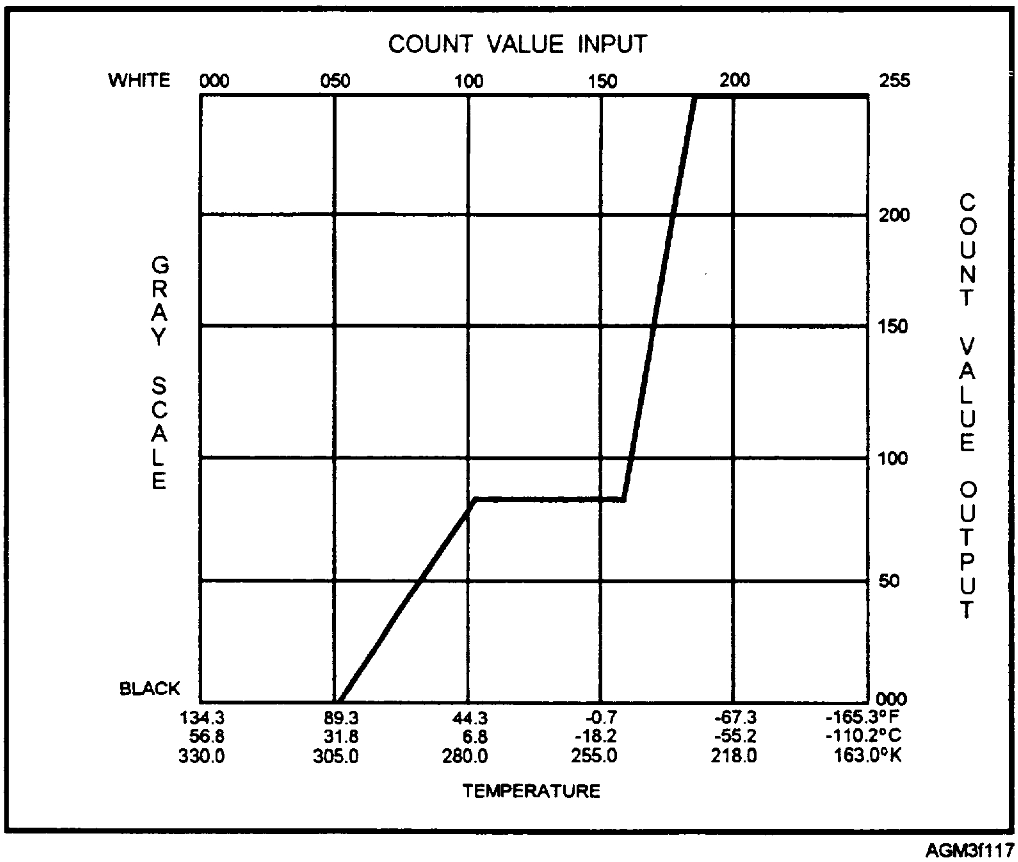


Figure 1-17.—High-low enhancement curve.

SPLIT ENHANCEMENT.—For split enhancements, two ranges are also selected. For each, the complete gray-shade and count value scale applies. This means that the complete gray shade scale is applied **twice** over the **image,** except for temperatures lying between the two defined ranges. Figure 1-18 displays a split enhancement curve for temperatures of +30°C to 0°C and -10°C to -30°C. Areas colder than the lower minimum temperature will appear white. Areas warmer than the higher maximum temperature will appear black. Areas which are temperatures between the upper and lower ranges will appear gray.

Predefined Enhancement Curves

Besides locally developed enhancement curves, there are several predefined enhancement curves available for GOES imagery that have been tested and evaluated over many years. Each of these enhancements was developed for a specific application. One of the most common is the MB Curve. This is a very good, all-purpose curve, but was specifically designed for summertime convective activity. The MB curve has very distinct contours (thresholding) around specific temperatures, and is especially helpful in picking out thunderstorms. Figure 1-19 shows the configuration of the MB curve. The *GOES* User's *Guide* contains detailed information on various predefined enhancement curves.

Visible imagery can also be enhanced by adjusting brightness values vice temperature values as with IR imagery. Enhanced visible imagery is especially useful in cases of fog and thick stratus.

GOES LEGEND INFORMATION

Much information about a particular GOES satellite image is available from the GOES legend that appears at the top of each image received over the GOES Telecommunications Access Program (GOES-TAP). An example of a GOES legend is shown at the

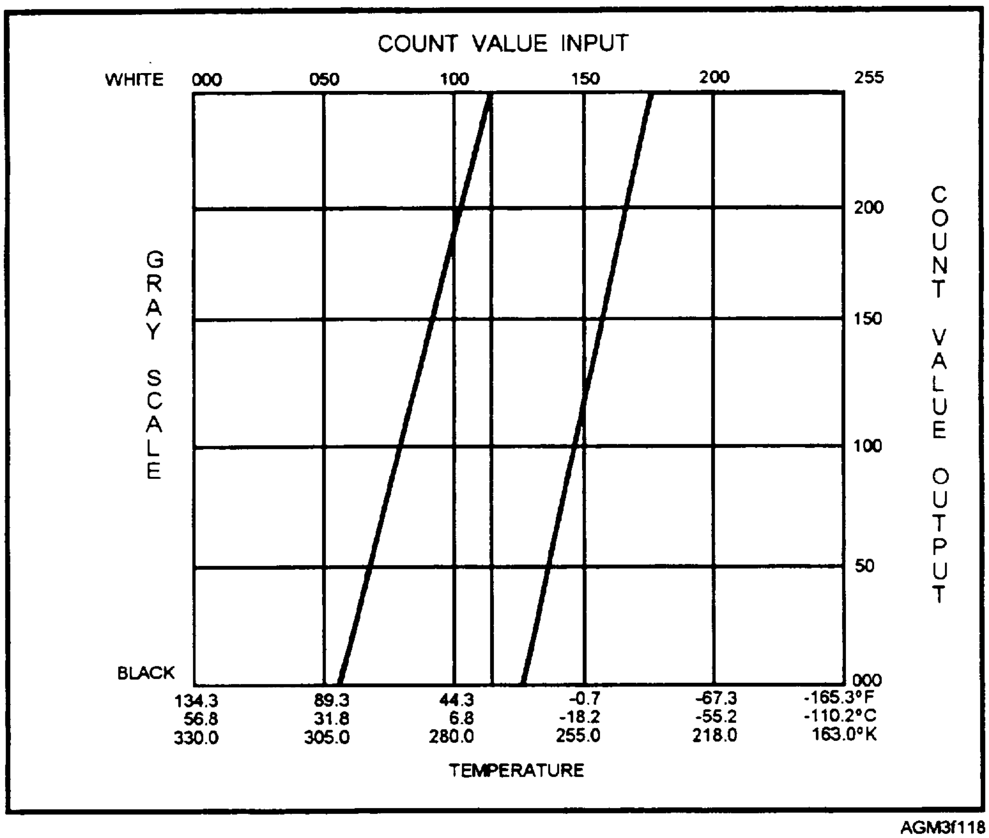
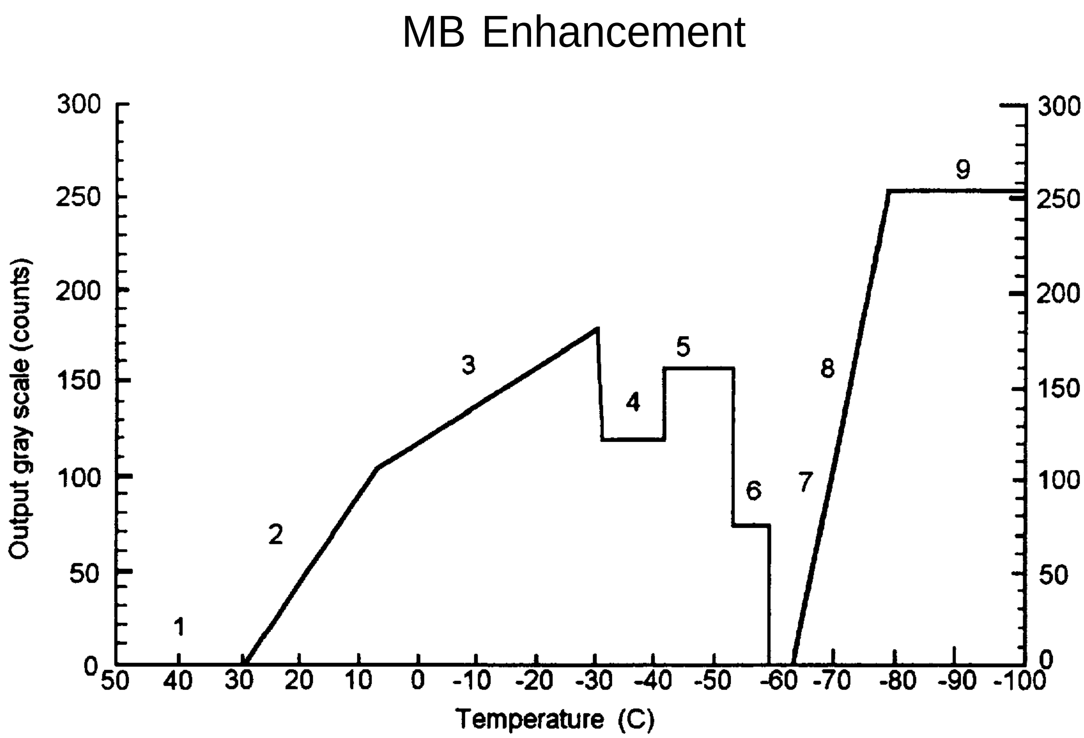


Figure 1-18.—Split enhancement curve.



Segment Number	Output count	Temperature Range (°C)	Comments
1	0 - 0	56.8 to 29.3	Little or no information
2	0 - 100	29.2 to 6.8	Surface features/warm clouds
3	101 - 176	6.7 to -31.2	Middle level clouds
4	117 - 117	-31.6 to -42.3	Cirrus/thunderstorms (Med gray)
5	155 - 155	-42.5 to -53.3	" " " (Light gray)
6	70 - 70	-53.6 to -59.4	" " " (Dark gray)
7	0 - 0	-59.7 to -63.1	" " " (Black)
8	0 - 255	-63.5 to -80.5	" " " (Repeat gray)
9	255 - 255	-81.1 to -110.1	" " " (White)

AGM3f119

Figure 1-19.—The GOES MB enhancement curve.

top of figure 1-20. Column 1 is the Universal Coordinated Time (UTC) and column 2 is the date of the image. The first number in column 3 indicates line stretcher/data buffer identification data and the first letter is the satellite identification indicator (I=GOES 8, J=GOES 9). The second letter in column 3 is the image type, which will be either "F" for full disk IR, "E" for the equivalent IR sector, or "A", "B", "C", "D" for the visible sectors. The next number in column 3 is the resolution in kilometers, and the last two letters in column 3 indicate the type of enhancement curve (IR imagery only). Columns 4 and 5 are for use by satellite specialists.

Column 6 of the GOES legend indicates the sector identification of the image. The term sector refers to the segments of a GOES image that are expanded or contracted to the desired geographic region of a particular GOES-TAP distribution site. The first letter indicates the satellite field distribution site for which

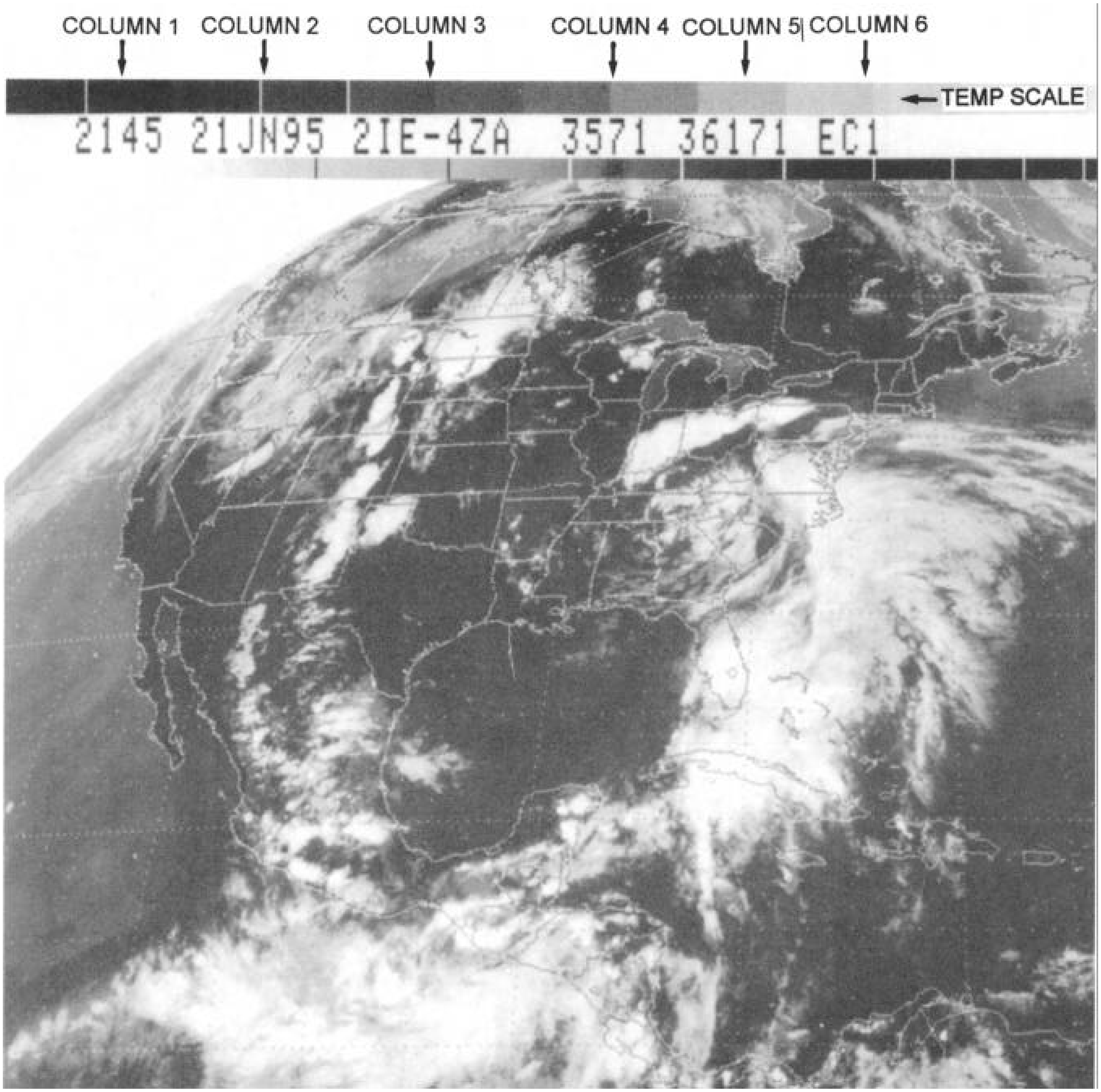


Figure 1-20.—A GOES 8 EC1 infrared sector taken at 2145 UTC, June 21,1995. The GOES legend is at the top of the image.

the sector was generated, such as "D" for Washington, D.C, or "S" for San Francisco. The next letter indicates the sector resolution in kilometers, that is A= 1 km, B = 2 km, C = 4 km, and D = 8 km (IR only). The last digit indicates the identification number of the specific sector.

GOES TEMPERATURE SCALE

The temperature scale appears only on IR and WV imagery, and it appears below the legend. The temperature scale is divided into 10°C increments with a range from +50°C to -100°C. It has 15 temperature blocks separated by white or black vertical lines. The temperature scale is very useful in cloud and non-cloud identification.

REVIEW QUESTIONS

Q25. What is the purpose of enhancing satellite imagery?

Q26. What is a major disadvantage of providing too much definition to user-defined enhancement curves?

Q27. Which type of user-defined enhancement curve applies two complete gray-shade and count value scales for two separate temperature ranges?

Q28. What is indicated in column 6 of the GOES legend?

Q29. The GOES temperature scale is normally divided into segments of how many degrees?

METHODS OF ACQUIRING IMAGERY

LEARNING OBJECTIVE: Identify the various methods used to acquire environmental satellite imagery.

There are several ways to receive satellite imagery: weather facsimile broadcast; Navy Oceanographic Data Distribution System (NODDS); GOES Telecommunications Access Program (GOES-TAP); satellite direct-readout service; weather facsimile service (WEFAX); the Internet; and AUTODIN message.

WEATHER FACSIMILE BROADCAST

Some ships may receive a low quality satellite image as part of the U.S. Coast Guard facsimile broadcast. Transmitted via high-frequency (HF) radio, this broadcast transmits National Weather Service charts and satellite imagery on a fixed schedule. Schedules and frequencies for facsimile broadcasts originating from CONUS stations (San Francisco, New Orleans, Boston, and Kodiak) are available over the Internet. Several other countries, such as Japan and India, also transmit weather charts and satellite imagery via HF. A listing of all maritime weather broadcast frequencies is available in the latest edition of *Worldwide Marine Radiofacsimile Broadcast Schedules* published by NOAA.

NAVY OCEANOGRAPHIC DATA DISTRIBUTION SYSTEM

The Navy Oceanographic Data Distribution System (NODDS) is a dial-up data service available from FNMOC. Although originally designed to transmit graphical data fields for portable computer systems, selected satellite imagery is now available within a few hours of sensing. Authorized users may access the system from anywhere in the world via computer modem through the U.S. Govemment-owned Internet routing networks or via direct long-distance telephone connection on commercial or Defense Switched Network (DSN) lines. Information on NODDS satellite imagery is available in the *Navy Oceanographic Data Distribution System Products Manual.*

All of the satellite data available on NODDS is from DMSP satellites. The pictures that actually appear on your computer monitor may not be quite as clear as imagery from other sources. The imagery is considered *near real-time* in that it is available to the user usually within a few hours of sensing. The DMSP satellites collect imagery, store the information as digital data aboard the satellite, and then dump the imagery data on command as it comes within range of a receiver site capable of copying high-resolution imagery. DMSP imagery for specific, high-interest areas around the world may be requested from FNMOC after some coordination.

GOES TELECOMMUNICATIONS ACCESS PROGRAM (GOES-TAP)

Ashore, Navy and Marine Corps weather stations receive satellite imagery primarily from the GOES-TAP service. The GOES-TAP service is operated by NESDIS, and satellite images are provided via dedicated telephone circuits. The circuits are leased from commercial telephone companies and are maintained by the telephone companies that own them. Routine satellite images are transmitted at 15-minute intervals. The imagery is normally displayed on a computer monitor that has control access to the various channels of the GOES-TAP system.

GOES-TAP users may be connected to one of several satellite field distribution facilities or be connected to another user.

When connected to a distribution hub, the user may select several different channels of imagery signals. There are several hubs located at various National Weather Service (NWS) forecasts offices, such San Francisco, Miami, and Kansas City, to name a few.

If the user is not connected directly to a hub, but connected to another user, this arrangement is appropriately called a slave connection. The secondary user has no direct choice of incoming imagery signal and only receives the data on the channel selected by the primary user. Several Navy and Marine Corps weather stations are connected as slaves. Slaved GOES-TAP users must coordinate with the primary user if a different channel of imagery is desired.

Each channel of GOES-TAP is a separate broadcast of imagery. One channel, for example, may contain only alternating visual and infrared GOES satellite images of the full disk (hemisphere) of the earth. Another channel may contain visual and infrared GOES images of only the southeastern United States. A third channel may contain imagery from the European METEOSAT. Yet another channel may contain high-resolution picture transmission (HRPT) imagery from a NOAA satellite. Enhanced infrared imagery from GOES is also routinely available via GOES-TAP.

Most GOES-TAP data is processed and analyzed by using a desktop computer with a color video monitor. The monitor is used to display both the imagery and the control menus. Initial issue equipment was the GOES-TAP Imaging System (GTIS), which used a Unisys 80386 desktop computer. Most of these systems have been replaced by the Meteorology and Oceanography (METOC) Integrated Data Display System (MIDDS). A laser printer may be connected to either system to provide hard copy prints of the imagery. Although hard copies of selected images may be made, hard copy quality is a function of the printer or imagery connected to the system. Similar equipment called the Naval Satellite Display System-Enhanced (or NSDS-E) is used at most NAVMETOCCOM centers. This system has the additional capability of copying NOAA polar-orbiter and DMSP imagery. Further changes to GOES-TAP processing equipment are very likely in the future.

Almost all satellite imagery processors have looper capability. The primary application of any looper system is to store and display a series of geostationary satellite images of the same area in a sequence that shows the movement of clouds and weather systems. Individual satellite images may also be displayed and studied. The various other display options, such as map overlay and enhancement, are menu-driven for both the GTIS and the MIDDS as is the channel selection. Instructions for using GTIS are contained in the User's Manual provided with each installation.

The MIDDS has a colorized custom enhancement function and a few systems have the additional capability of obtaining satellite images via WEFAX broadcast, HF radio, or Automatic Picture Transmission (APT) receiver. Instructions for obtaining satellite information via MIDDS is contained in the *Meteorology and Oceanography (METOC) Integrated Data Display System (MIDDS) User's Guide.*

DIRECT-READOUT SERVICE

Direct-readout service is an image-data transmission designed to be received by user-operated satellite receiver stations, such as the AN/SMQ-11 satellite terminal and the Interim Mobile Oceanography Support System (IMOSS) satellite module. The raw satellite signals are converted to an image by the receiver station. Direct-readout service is available from all polar-orbiting meteorological satellites. This service is generally not available from geostationary satellites, although a few weather activities have acquired geostationary direct-readout systems from commercial contractors.

One type of direct-readout service that is provided by the NOAA satellites is the *Automatic Picture Transmission* (APT) service. APT service provides a continuous transmission of both visual and infrared satellite imagery. The NOAA satellites transmit a pair of images, one visual and one infrared, over sunlight portions of the earth, and two different infrared channels over the dark side of the earth. The scan rate is 120 lines per minute at 4-kilometer resolution. The amount of data received by a station depends on the location of the satellite subpoint; the further the subpoint falls from the station, the smaller the area of coverage becomes.

The received APT images are *ungridded*—no latitude/longitude lines nor land/water or geographical boundaries are added to the image (fig. 1-21). APT service is also available from foreign polar-orbiting

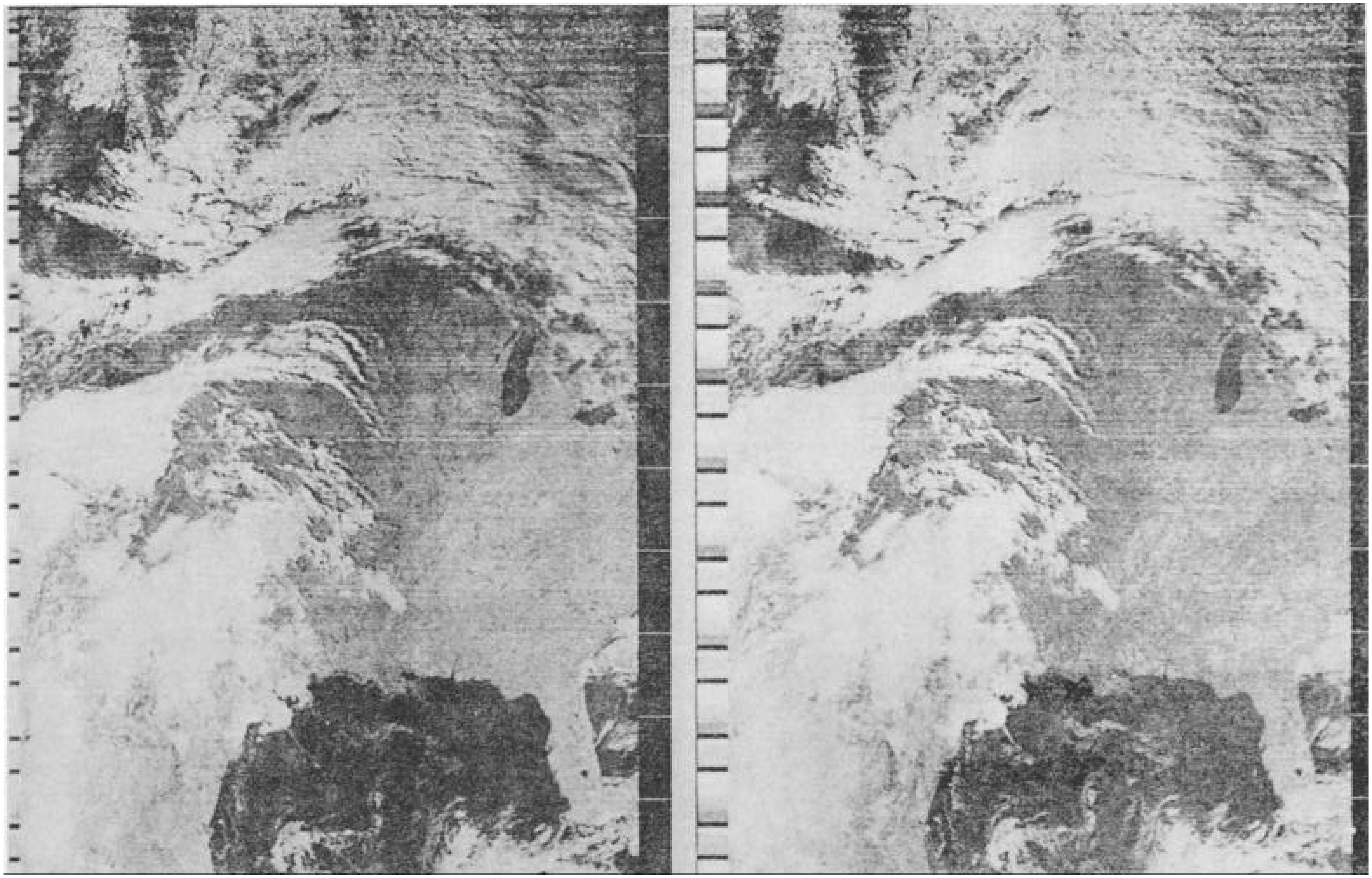


Figure 1-21.—Typical APT visual and infrared image pair from a NOAA satellite.

satellites and varies from relatively low resolution to high resolution.

APT direct-readout imagery is normally transmitted in the 136-MHz to 139-MHz band. The data signals are transmitted from the satellite to earth within seconds of being scanned by the satellite sensors. This is sometimes called *real-time* imagery; the image is available as the satellite scans the earth. APT service is designed to be received by anyone with a standard, relatively low-cost satellite receiver. Signals from DMSP satellites also provide APT. However, the signals are encrypted. Additional information on APT direct-readout services may be found in the *NOAA KLM User's Guide.*

The IMOSS satellite module can receive, process, display, grid, and enhance APT direct-readout service from nearly all polar-orbiting environmental satellites. It is not equipped to decrypt the imagery signal from the DMSP satellites. The AN/SMQ-11 is capable of copying both APT data as well as DMSP encrypted signals.

A second type of direct-readout service available from both the NOAA and DMSP satellites is the *High-Resolution Picture Transmission (HRPT)* service. This is data scanned at a rate of 360 lines per minute to provide 1.1-kilometer resolution (fig. 1-22). High-resolution imagery can be, and usually is, transmitted from satellites as a continuous broadcast. HRPT

Figure 1-22.—HRPT imagery.

imagery, like the APT direct-broadcast imagery, is received unprocessed and ungridded. Many user-operated satellite receiver systems are unable to receive and process I-IRPT imagery. The IMOSS satellite module cannot receive or process HRPT, while the AN/SMQ-11 is able to receive and process the signal.

High-resolution imagery may also be stored aboard the satellite, downloaded to a Command Data Acquisition (CDA) station on command, and sent to NESDIS in Suitland, Maryland. NESDIS processes the imagery, adds gridding, and forwards the processed signal to other imagery services. NESDIS operates two CDA stations for both the NOAA and GOES satellites: Wallops Island, Virginia, and Fairbanks, Alaska. The Department of Defense operates its own CDA stations for the DMSP satellites.

WEFAX SERVICE

Another method for receiving satellite imagery at your ship or station is to copy a WEFAX (weather facsimile) broadcast from a geostationary satellite. WEFAX is the *retransmission* of low-resolution infrared and visible satellite imagery from U.S. GOES satellites to any receiver capable of copying the signal. WEFAX transmissions are also available via METEOSAT, GMS, and other foreign satellites.

The U.S. GOES WEFAX service provides visual and infrared sectors as well as full disk imagery. The service also includes selected meteorological and oceanographic charts, TBUS bulletins, and operational messages. You can check the NOAASIS web site for information on active WEFAX broadcasts, broadcast content, and frequencies. Information concerning GOES schedules is also available via the Internet. Detailed information on WEFAX services is provided in the *WEFAX User's Guide* issued by NOAA/NESDIS.

Each GOES satellite provides high-resolution imagery that is transmitted on a high-frequency signal to the CDAs and processed at NESDIS. NEDSIS processes the signal to add gridding (latitude/longitude), geographical boundaries, borders for land and water masses, and enhancement. The CDAs then retransmit the processed signal back to the satellite for WEFAX transmission. In turn, the satellite retransmits the WEFAX signal back to earth on a lower frequency signal for reception by user-operated satellite receivers. The service is generally provided at frequencies near 1691 MHz.

The WEFAX signal is much weaker than the APT or HRPT signal from polar-orbiting satellites. Normally, a directional antenna with antenna polarity control circuits is necessary to copy the WEFAX signal. The AN/SMQ-11 is fully capable of capturing the WEFAX signal. The IMOSS satellite module can also receive and process the WEFAX signal by using a special directional antenna specifically designed to copy the broadcast.

Directional antennas should be aimed at the broadcasting geostationary satellite for the best WEFAX reception. Instructions for aiming the IMOSS WEFAX antenna are available in the *Interim Mobile Oceanography Support System (IMOSS) User's Guide*. Appendix C of the guide contains diagrams for calculating elevation and azimuth angles for different geostationary satellites.

Be aware that although international agreements call for five operational geostationary satellites, problems occasionally arise that require satellites to be moved temporarily to slightly different locations. WEFAX may also be broadcast from older geostationary satellites that have been moved out of the primary position. Figure 1-23 is a diagram frequently used to calculate the azimuth (degrees true) and elevation angles needed to find any geostationary satellite located over the equator.

To use the diagram, the user subtracts the longitude of the receiver location (site longitude) from the longitude of the satellite to find delta (Δ), (ignore the sign). Using the value of Δ (scale on the left side of the diagram with 80 degrees at the bottom and 3 degrees at the top), follow parallel to the drawn lines sloping downward toward the right. Using the receiver station latitude (site latitude) on the Γ scale (right side of the diagram), follow parallel to the lines sloping downward toward the left to the intersection of the Δ value. The antenna elevation angle (look elevation) is found by drawing a horizontal line toward the left to the *look elevation* scale. The antenna azimuth is found by drawing a vertical line downward to the *look azimuth* scale. The four azimuth scales are used as follows:

- SW - When receiver is **south** of the equator and **west** of the satellite's position
- SE - When the receiver is **south** of the equator and **east** of the satellite's position
- NE - When the receiver is **north** of the equator and **east** of the satellite's position

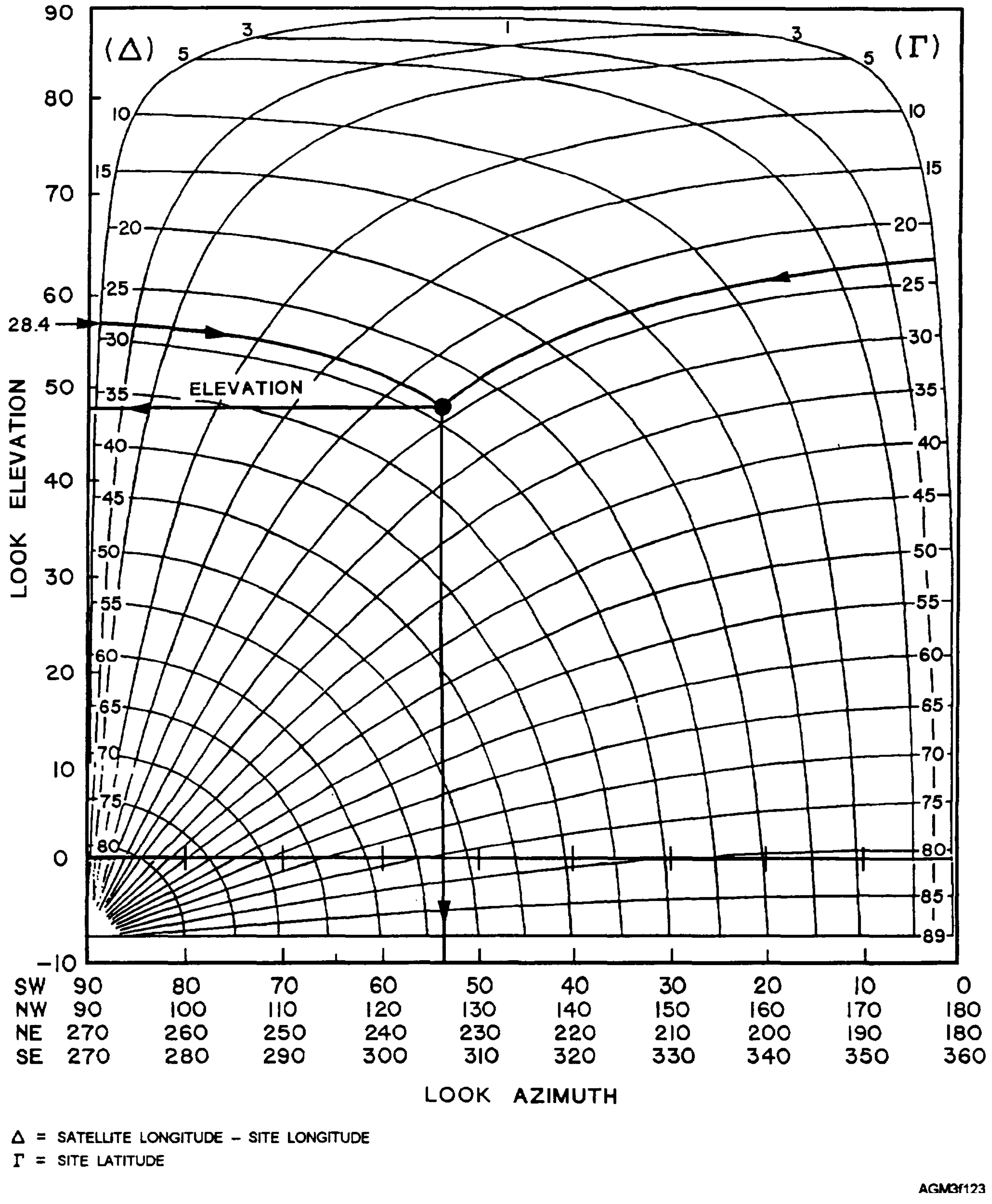


Figure 1-23.—Geostationary satellite antenna-aiming diagram.

- NW - When the receiver is north of the equator and west of the satellite's position

In the example shown on the diagram, azimuth and elevation angles are determined for the 75°W GOES from a receiver site at 103.4°W longitude, 23.0°N latitude. The Δ value of 28.4° is the difference between 103.4° and 075.0°, ignoring the sign. The antenna elevation is about 48 degrees, and the azimuth on the NW scale is 126 degrees.

INTERNET

In recent years, the Internet has become a very efficient method of acquiring satellite imagery. The worldwide web is the fastest way to acquire a wide variety of real-time satellite imagery. NOAA/NEDSIS has its own website (NOAASIS) along with several private companies and universities. Of particular importance is that these sites can be reached aboard ships equipped with Internet access. FNMOC can also transmit satellite imagery over the military Internet (NIPRNET and SIPRNET). This imagery can then be viewed using Joint METOC Viewer (JMV) software with any computer system able to process the data. Details on the JMV and the NIPRNET/SIPRNET routing networks is covered in later modules. The Naval Research Laboratory in Monterey, California, has an outstanding Internet homepage that provides a tremendous amount of satellite imagery data. It contains general information relating to environmental satellites and provides guidance packages for new and experimental satellite products. The website also provides links to various other satellite imagery sources.

AUTODIN MESSAGE

The Automatic Digital Network (AUTODIN) is the U.S. Navy's most common method of transmitting message traffic between commands. Satellite images can also be sent via AUTODIN in greatly compacted form. This method is only used in rare cases, most often used by at-sea platforms with little or no environmental satellite reception capability and no Internet access. Portions ofreceived images that are of interest to a ship can be extracted, compacted, encoded for transmission, and sent via AUTODIN link to the ship from any other command (normally Meteorology and Oceanography centers). The AUTODIN encoded images are then available for reprocessing and display by the ship. Requests for satellite imagery via AUTODIN are carried out on a case-by-case basis. Requests should be limited to information that is essential to operations, as too much data will slow other AUTODIN message traffic.

REVIEW QUESTIONS

Q30. Which U.S. Government agency provides HF broadcasts of satellite imagery?

Q31. What type of satellite imagery is available from NODDS?

Q32. How is satellite imagery acquired by most shore-based weather stations?

Q33. What is the purpose of a satellite looper?

Q34. What is the advantage of APT direct-readout imagery?

Q35. How does the resolution between APT and HRPT data compare?

Q36. What type of information is available from the WEFAX broadcast?

Q37. What is the fastest way to acquire a wide variety of satellite imagery?

Q38. How can units with no environmental satellite reception capability or Internet access still receive satellite imagery?

SATELLITE RECEIVER SYSTEMS

LEARNING OBJECTIVES: Identify the two primary satellite receiver systems used to acquire direct-readout imagery and WEFAX products. Identify the operator's manuals that provide detailed instructions for use of the systems.

Two satellite receiver systems are routinely operated by Navy and Marine Corps weather observers. The AN/SMQ-11 system is used at major shore installations and aboard all aircraft carriers. Navy Mobile Environmental Teams (METs) use the optional satellite module of the IMOSS to receive satellite imagery.

AN/SMQ-11 METEOROLOGICAL DATA SET

The AN/SMQ-11 satellite receiver station is installed aboard most U.S. Navy ships staffed by Aerographer's Mates, at many Naval Meteorology and Oceanography Command activities, and in Marine Corps Mobile Meteorological Vans (METVANs). The ANISMQ-11 may receive, process, display, grid, and enhance DMSP imagery and both APT and HRPT direct-readout imagery. The system can also receive WEFAX imagery, but cannot command a data download of stored HRPT data. The AN/SMQ-11 produces imagery on dry-silver film (which requires no chemicals for development), or by using a high-resolution laser printer.

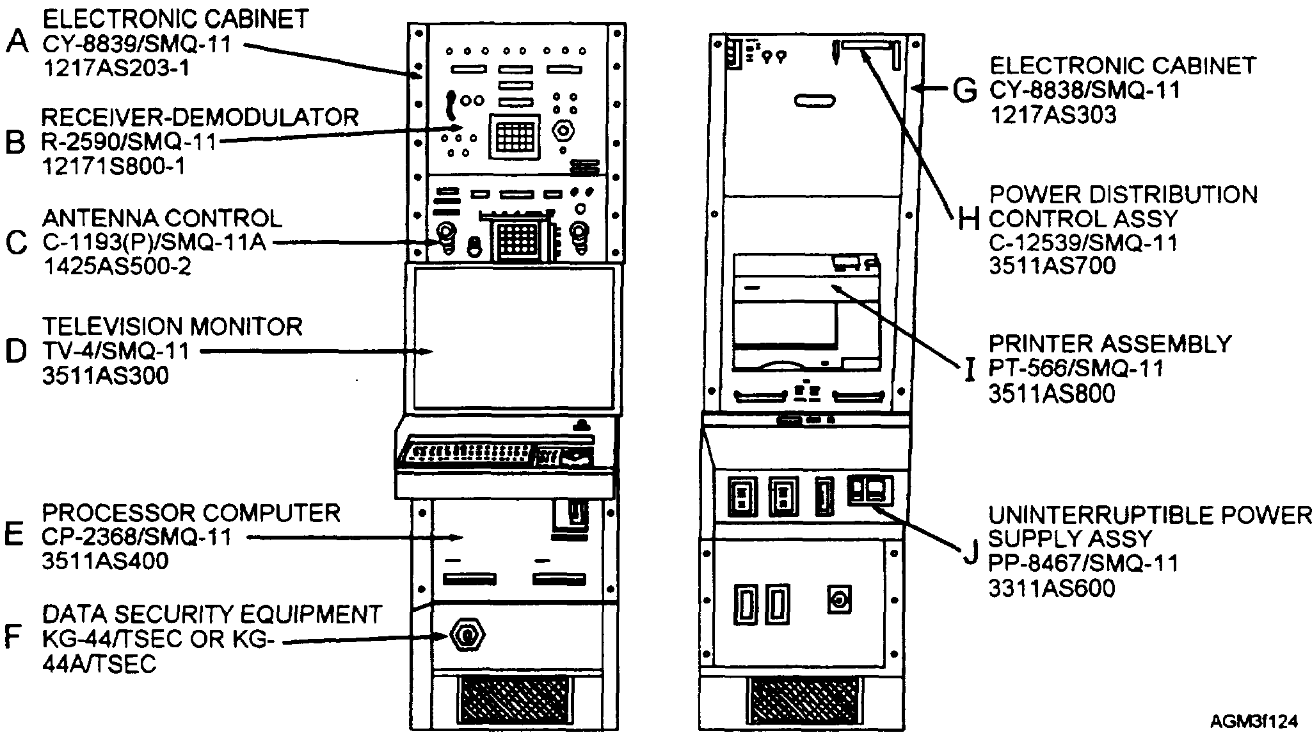
Figure 1-24 shows the two AN/SMQ-11 equipment cabinets that are installed inside the workspaces. Each AN/SMQ-11 is equipped with a Tactical Advanced Computer, Version Four (TAC-4), that includes a workstation, color monitor, an uninterruptible power supply, and a power distribution unit. The ANLSMQ-11B has a dual frequency array antenna (figure 1-25) and is normally installed on a rooftop ashore. Some systems are equipped with a multi-frequency array antenna (ANLSMQ-11C). The shipboard version of the AN/SMQ-11 contains additional circuits for control and stabilization of the antenna to compensate for ship motions. Operation of the ANISMQ-11 is described in detail in NAVAIR 50-30SMQ-11, *Organizational Maintenance with Illustrated Parts Breakdown, Receiver/Recorder Set, Meteorological Data, AN/SMQ-11.* This manual includes operator instructions.

At most sites, the AN/SMQ-11 satellite receiver system is cross connected to the Tactical Environmental Support System (TESS). Imagery received by the AN/SMQ-11 may be "called into" the TESS terminal for processing, display, and analysis. Additionally, much of the operation and control of the AN/SMQ-11 can be performed through the TESS keyboard.

The directional antenna of the AN/SMQ-11 system must be aimed at the satellites to receive either direct-readout imagery or GOES and WEFAX broadcasts. The aiming operation is performed automatically by the system, provided the ephemeris data has been entered properly for each polar-orbiting satellite, and the position data has been updated for the geostationary satellites.

IMOSS SATELLITE MODULE

The Interim Mobile Oceanography Support System (IMOSS) is a combination of three



A. Electronic Cabinet CY-8839/SMQ-11
B. Receiver-Demodulator R-2590/SMQ-11
C. Antenna Control C-l1933(P)/SMC-11
D. Television Monitor TV-4/SMQ-11
E. Processor Computer CP-2368/SMQ-11
F. Data Security Equipment KG-44/TSEC
G. Electronic Cabinet CY-8838/SMQ-11
H. Power Distribution Control Assembly C-12539/SMQ-11
I. Printer Assembly PT-566/SMQ-11
J. Uninterruptible Power Supply Assembly PP-8467/SMQ-11

Figure 1-24.—AN/SMQ-11 equipment cabinets.

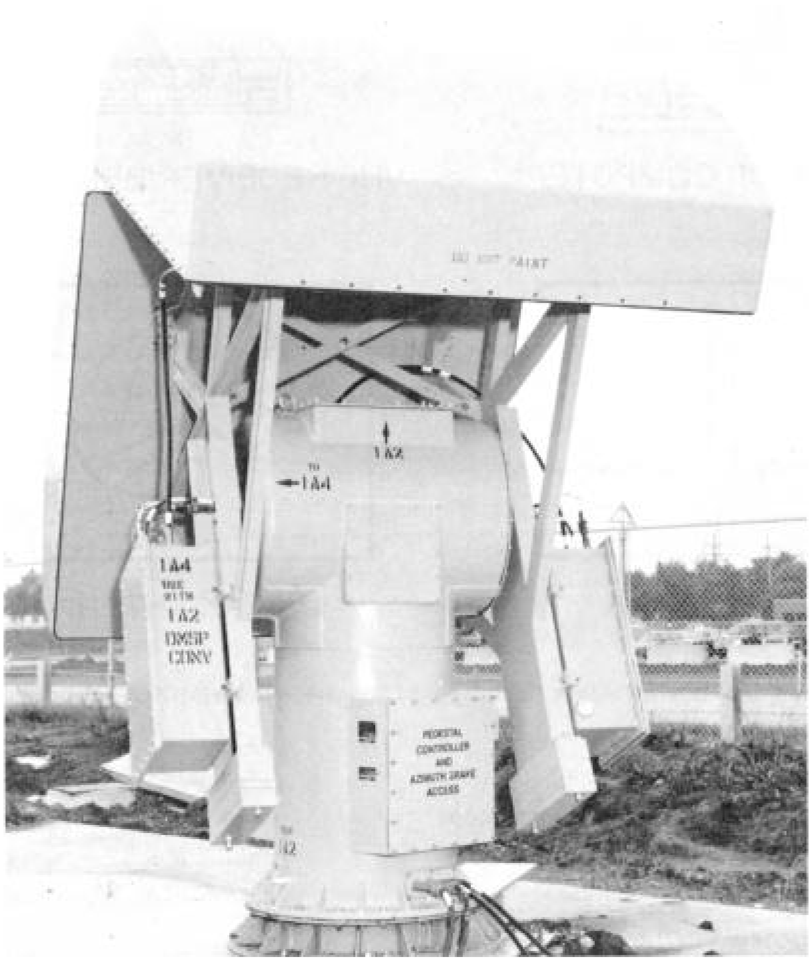


Figure 1-25.—AN/SMQ-11 dual frequency array antenna.

subsystems, the main subsystem, the communications module subsystem (COMM MOD), and the satellite module subsystem (SAT MOD). Each subsystem consists primarily of a laptop computer that can be used as a stand-alone system, depending upon mission requirements. The main subsytem contains a multiple application software library dedicated to many aspects of METOC support. The IMOSS comes equipped with a printer.

The SAT MOD consists of a laptop computer that contains a built-in satellite receiver and processor. It also includes a VHF receiver/demodulator and two antennas. One antenna is an omnidirectional antenna used to copy APT signals and the other is used to copy signals from the WEFAX broadcast. The SAT MOD is equipped with special software modifications that can be used independently from the main IMOSS computer. Satellite imagery received via the satellite module may be transferred to the main IMOSS computer by using a 1.44MB data disk. All components are equipped with protective cases (fig. 1-26).

Because the APT antenna is omnidirectional, no antenna aiming is required to track polar-orbiting satellites or geostationary satellites. When the system is powered up, the receiver will automatically scan satellite frequencies, detect imagery signals, and acquire the imagery. The WEFAX antenna must be manually oriented toward the geostationary satellite during initial setup of the system. For planning, the system contains software that displays orbital predictions and line-of-sight receiver ranges for the polar-orbiting APT and geostationary satellite WEFAX transmissions. Menu options on the liquid crystal display (LCD) screen guide the operator

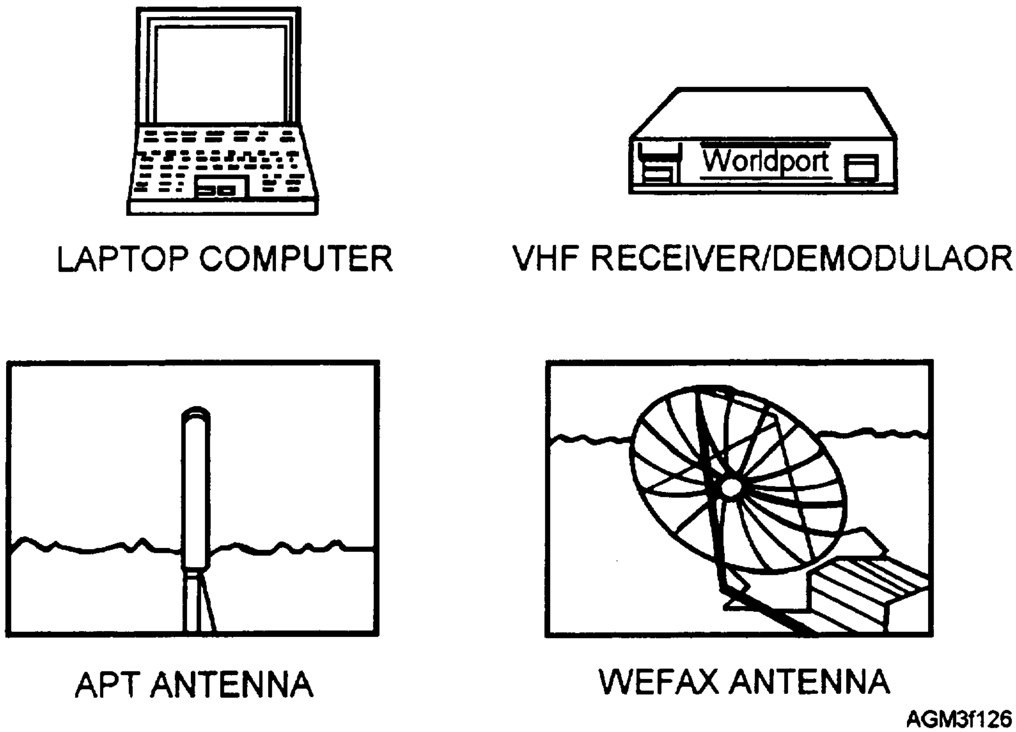


Figure 1-26.—Interim Mobile Oceanography Support System (IMOSS) satellite module.

through processing, gridding, and enhancement options for various APT direct-readout and WEFAX imagery.

The operator must update satellite ephemeris data for each polar-orbiting satellite at least once every 2 weeks. Selected prediction information from Part IV of the TBUS or NASA-2 line bulletins may be manually entered via the keyboard or copied directly from a data disk. Orbital-prediction information is available via message over the Automated Weather Network (AWN), by standard AUTODIN message, or by using a computer modem connection to various sources, such as the Internet.

Complete information on the operation of the IMOSS satellite module, including antenna orientation procedures, updating ephemeris data, gridding, and display of satellite imagery is contained in the IMOSS user's guide. The manual is provided with each module by the Naval Oceanographic Office.

REVIEW QUESTIONS

Q39. Which types of satellite imagery may be acquired by using the AN/SMQ-11?

Q40. Which types of satellite imagery may be acquired by using the IMOSS satellite module?

Q41. Which satellite antenna of the IMOSS satellite module must be manually oriented towards geostationary satellites?

EPHEMERIS INFORMATION

LEARNING OBJECTIVES: Identify the various orbital prediction bulletins and explain how they are obtained. Recognize how data from satellite orbital prediction bulletins is used to update user-operated satellite receivers.

One of the most critical operations on any of the direct-readout satellite imagery receiving systems is the updating of ephemeris data. *Ephemeris data* is information that describes the type, orientation, and shape of a particular satellite's orbit. Ephemeris data is critical to satellite tracking as it provides key information that allows you to determine where a satellite will be located at any given moment. This information is also used to allow the receiver system to predict where polar-orbiting satellites will be at any moment in relation to the location of the receiver site. More importantly, ephemeris information enables your receiver system to *earth-locate* the image, that is, to establish what area of the earth is depicted in an image received from a polar-orbiting satellite. Once an image has been earth-located, you can then merge appropriate geographical boundaries and a latitude/longitude grid with the image. Without accurate placement of a grid system, even the clearest high-resolution images are nothing more than interesting pictures. Environmental applications require the analyst or forecaster to be able to determine where a feature is and how fast it is moving, which is an impossible task without an accurate reference grid.

Since geostationary satellites do not move relative to the earth, their ephemeris data does not need frequent updates. However, they are moved periodically and their positions are updated via special bulletins as necessary. These bulletins are posted on the Internet at the NOAASIS web site.

Several software programs are in use in various systems to automatically calculate polar-orbiting satellite orbits and antenna-aiming data. The AN/SMQ-11 system and the SAT MOD both perform these functions, but rather differently. TESS, which may be used to control the AN/SMQ-11, also has a separate orbital prediction function. Software upgrades are in development that will alleviate some of these differences.

In this section, we will discuss how to interpret various elements of ephemeris information from the most common polar-orbiting satellite prediction bulletins. The exact information required, as well as data entry methods for each system, are discussed in the individual operator's manuals.

Ephemeris data for each polar-orbiting satellite is available from several sources. Information for the NOAA satellites is available from the National Weather Service telecommunications center as NOAA APT Predict bulletins and from NASA as Two-Line Orbital Elements bulletins. Orbital information for the DMSP satellites and all foreign-operated, polar-orbiting satellites is available from the Naval Space Surveillance Center, Dahlgren, Virginia, as *C-Element Orbital Data* and *Satellite Equator Crossings* bulletins.

NOAA APT PREDICT BULLETINS (TBUS)

NOAA APT Predict bulletins, because of the message's data identifier TBUS, are more commonly referred to as TBUS data. These bulletins are routinely provided over the WEFAX broadcast and the automated weather network (AWN). They are also available on the meteorological/oceanographic data channel of the fleet multichannel communications broadcast, as well as via AUTODIN message. TBUS data can also be obtained from the Internet through the NOAASIS website.

The TBUS bulletins are in a special U.S. national code form. The code form is only used for orbital prediction information for satellites operated by the United States. Complete information on this code is available in the *NOAA KLM User's Guide.* Satellites in the TBUS bulletin are identified in the message header by name, such as NOAA 14, and by the U.S. satellite identification number, such as 37 for NOAA 12, and 38 for NOAA 14. In Part IV of the bulletin, the satellites are identified by an internationally recognized satellite number, such as 1994 089A for NOAA 14.

A separate NOAA APT predict bulletin is composed daily for each operational NOAA series satellite. TBUS 1 bulletins are used to indicate north to south (descending) daylight orbits, and TBUS 2 bulletins are used to indicate south to north (ascending) daylight orbits. Each bulletin is composed of six parts:

- Part I contains equator-crossing reference information.
- Day Part II contains satellite altitude and subpoint coordinates in 2-minute intervals for reference orbits over the Northern Hemisphere in the sunlight portion.
- Day Part III contains the altitude and subpoint coordinates for the portion of the reference orbits over the Southern Hemisphere in the sunlight portion.
- Night Part II contains 2-minute coordinates for the portion of the orbit over the Northern Hemisphere in the dark sector.
- Night Part III contains coordinates for the portion of the orbit over the Southern Hemisphere in the dark sector.
- Part IV contains high-precision orbital calculation elements, transmission frequencies, and remarks.

Parts II and III (day and night) are useful only when satellite orbits must be manually plotted and will not bediscussed further. TESS requires information from both Parts I and IV, while the SAT MOD and AN/SMQ-11 require only information from Part IV.

Table 1-2.—Typical NOAA APT Predict Bulletin

TBUS 2 KWBC 021900
APT PREDICT
MMDDSS
010538 NOAA 14
PART I
$0N_rN_rN_rN_r$ $0D_rD_rH_rH_r$ $0m_rm_rs_rs_r$ $Q_rL_oL_oL_oL_o$ Tmmss $LL_oL_oL_oL_o$
05551 00515 05539 02127 T0203 L2551 (Reference Orbit)
$N_4N_4N_4N_4H_4$ $H_4m_4m_4s_4s_4$ $Q_4L_oL_oL_oL_o$
55552 24353 12333 (Fourth Orbit)
$N_8N_8N_8N_8H_8$ $H_8m_8m_8s_8s_8$ $Q_8L_oL_oL_oL_o$
55590 53207 23461 (Eighth Orbit)
$N_{12}N_{12}N_{12}N_{12}H_{12}$ $H_{12}m_{12}m_{12}s_{12}s_{12}$ $Q_{12}L_oL_oL_oL_o$
55631 22021 33255 (Twelfth Orbit)
DAY PART II ...
DAY PART III ...
NIGHT PART II ...
NIGHT PART III ...
PART IV
AAAAAAAAA BBBBB CCCCCCCCCCCC DDEEFFGGHHIIIII JJJJJJ
1994 089A 15472 365064564372 971231013258362 1227653
KKKKKKKK LLLLLLLL MMMMMMMM NNNNNNNN OOOOOOOO PPPPPPPP
01020047 01020594 00098964 09699662 31704580 09902079
QQQQQQQQ RRRRRRRR SSSSSSSSS TTTTTTTTT UUUUUUUUU
26324050 07228814 P052955506 M049302836 M000000000
VVVVVVVVV WWWWWWWWW XXXXXXXXX YYYYYYYYY ZZZaaabbb cccc
M00803903 M00840889 P07331793 004218509 104094004 9449
dddddddddd eeeeeeeee fffffffff ggggggggg hhhhhhhh $L_oL_oL_ol_ol_ol_ol_o$
0000500000 M00272363 P00100495 P00508212 19428046 13702451
iiiii jjjjjj kkkkkk llllll mmmmmm nnnnnn oooooo
102897 M00110 121597 M00700 120197 P00010 032498
APT TRANSMISSION FREQUENCY 137.62 MHZ
HRPT TRANSMISSION FREQUENCY 1707.0 MHZ
BCN (BEACON) DSB FREQUENCY 137.77 MHZ
APT DAY/NIGHT 2,4. VIS CH 2 /0.725 TO 1.0/ AND IR CH 4 /10.5 TO 11.5/ XMTD
DURING S/C DAY. IR CH3 /3ND IR CH 4 /10.5 TO 11.5/ XMTD
DURING S/C NIGHT. DCS CLK TIME YR/DA/TIM 1995 021 79186.656.
BT

Table 1-2 shows a typical TBUS bulletin with the information in Parts II and III deleted. We have added a symbolic code form in italics to help you understand what information is included in the message. Table 1-3 references this symbolic code form and identifies the information. We have concentrated on the information needed for input to the various ephemeris update programs currently in use. Appendix II is a diagram of the octants of the globe.

Directly under the APT Predict line is an identifier for the date of the beginning of the prediction period and the U.S. satellite identification number. In our example in the table, 0105038 means the prediction period begins on January 05 (0105) for satellite 38 (NOAA 14). The orbital predictions are carried out to several days. Note that the message date-time-group 021900 shows that the bulletin is transmitted 3 days before the prediction period covered by the message.

Table 1-3.—Explanation of Important TBUS Bulletin Elements

TBUS MESSAGE HEADER		
MMDDSS: Prediction start- *MM*=Month, *DD*=Day, *SS*=U.S. Satellite number		
TBUS MESSAGE PART I		
$0N_rN_rN_rN_r$:	0	= Code group indicator for first three groups $N_rN_rN_rN_r$= reference orbit #
$D_rD_rH_rH_rm_rm_rs_rs_r$:		Reference orbit equator crossing time (UTC): D_rD_r= day, H_rH_r= hour, m_rm_r= minute, s_rs_r= second
$Q_rL_oL_oL_oL_o$:	Q_r	= Octan t satellite is entering after crossing equator on reference orbit $L_oL_oL_oL_o$ = Reference orbit equator crossing longitude in degrees and hundredths of a degree
Tmmss		Nodal period: *T* = indicator, *mm* = minutes, *ss* = seconds (hundreds grou will not be included; 100 min. 13 sec. will be coded as 0013)
$LL_oL_oL_oL_o$:		Nodal Increment: *L* = indicator, $L_oL_oL_oL_o$ = degrees and hundredths of degrees longitude between successive equator crossings
$N_4N_4N_4N_4$		Orbit # of 4th (8th or 12th) orbit after reference orbit
$H_4H_4m_4m_4s_4s_4$:		Time (UTC) in hours, minutes, and seconds of satellite equator crossing 4th, (8th or 12th) orbit after reference orbit
$Q_4L_oL_oL_oL_o$:	Q_4	= Octant satellite is entering after crossing equator on 4th (8th or 12th) orbit after reference orbit $L_oL_oL_oL_o$ = Equator crossing longitude after reference orbit
TBUS MESSAGE PART IV		
AAAAAAAAA	=	International satellite identification
BBBBB	=	Orbit number at epoch
CCCCCCCCCCCC	=	Time of the first ascending node, in days, from the beginning of the year (9 decimal places)
DDEEFFGGHH	=	Epoch calendar date/time: *DD*= Year, *EE*= month, *FF*= day,
IIIII	=	*GG*= hour, HH= minutes, and *IIIII*= seconds (3 decimal places).
JJJJJJJ	=	Apparent Greenwich Hour Angle at epoch (4 decimal places)
KKKKKKKK	=	Mean period of anomaly (min) (4 decimal places
LLLLLLLL	=	Nodal period (min) (4 decimal places)
MMMMMMMM	=	Eccentricity (8 decimal places)
NNNNNNNN	=	Argument of perigee (deg) (5 decimal places)
OOOOOOOO	=	Right Ascension of ascending node (deg) (5 decimal places)
PPPPPPPP	=	Inclination (deg) (5 decimal places)
QQQQQQQQ	=	Mean anomaly (deg) (5 decimal places)
RRRRRRRR	=	Semi-major axis of orbit (km) (3 decimal places)
SSSSSSSSSS	=	*Epoch X position component (km) (4 decimal places)
TTTTTTTTT	=	*Epoch Y position component (km) (4 decimal places)
UUUUUUUUUU	=	*Epoch Z position component (km) (4 decimal places)
VVVVVVVVV	=	*Epoch X velocity component (km/sec) (6 decimal places)
WWWWWWWWW	=	*Epoch Y velocity component (km/sec) (6 decimal places)
XXXXXXXXX	=	*Epoch Z velocity component (km/sec) (6 decimal places)
YYYYYYYYY	=	Ballistics coefficient CD-A/M (m^2/kg), to eight decimal places
ZZZ	=	Daily solar flux value (10.7 cm) 10^{-7} W/m^2
aaa	=	90-day running mean of solar flux 10^{-7} W/m^2
bbb	=	Planetary magnetic index (2×10^{-5} gauss)
cccc	=	Drag modulation coefficient, to four decimal places
dddddddddd	=	Radiation pressure coefficient (m^2/kg), to ten decimal places
eeeeeeeee	=	*Perigee motion (deg/day) (5 decimal places)
fffffffff	=	*Right Ascension of the Ascending-Node motion (deg/day) (5 decimal places)
gggggggg	=	*Rate of change of mean anomaly at epoch (deg/day), (2 decimal places)
hhhhhhhh	=	Equator crossing longitude of the epoch reference orbit measure as East longitude, (5 decimal places)
iiiiii	=	Month, date and year (MMDDYY) of last TIP clock correction
jjjjjj	=	*Clock error after last correction measured in seconds (to three decimal places)
kkkkkk	=	Month, date and year (MMDDYY) of current clock error
llllll	=	*Current clock error measured in seconds (three decimal places)
mmmmmm	=	Month, date and year (MMDDYY) of the measured clock error rate
nnnnnn	=	*Clock error rate expressed as milliseconds/day
oooooo	=	Month, date and year (MMDDYY) of next TIP clock correction (000000 if unknown)
* signed values; *P* for positive, *M* for negative		

In the TBUS bulletin Part IV, all information necessary to calculate a satellite's orbit and variations in the orbit is provided. This information includes an epoch orbit number, two forms of an epoch date, position and velocity coordinates, the nodal period, and anomaly values used to determine the change in position of the satellite over any period of time.

SAT MOD Ephemeris Updates

Like the TESS, the SAT MOD may update ephemeris information by reading a TBUS message file. If the appropriate TBUS bulletin is not available directly from a disk file, the system may be updated with manual entries by using information in the TBUS bulletins. Only certain elements from each TBUS bulletin are required for each satellite in the SAT MOD. The resulting ephemeris files need only be updated every 2 weeks. Instructions for imputing TBUS bulletin data is contained in the IMOSS user's guide.

TESS Ephemeris Updates

TESS allows satellite ephemeris data files to be updated manually by entering selected data via the keyboard. TESS, interfaced with a communications system, may be directed to read a saved TBUS message file to automatically update ephemeris information. TESS may only use each particular TBUS bulletin during a 7-day valid period following the prediction date; in this case January 05 to January 12. Since predict bulletins are sent out daily, TESS may store more than one file of ephemeris information for each satellite, and prediction periods may overlap.

AN/SMQ-11 Ephemeris Updates

The AN/SMQ-11 does not have the capability to interpret imported TBUS messages to update its ephemeris files. Various parameters from the TBUS bulletin Part IV may be manually entered. The SMQ-11 requires the epoch calendar date-time-group be entered vice the epoch decimal date-time-group.

NASA TWO-LINE DATA

Another predict message is the NASA Two-Line Orbital Elements (TLE) bulletin. This bulletin contains orbital information very similar to Part IV of the TBUS bulletin. The message is divided into 16 elements and can be input into the SAT MOD and AN/SMQ-11 in lieu of TBUS data. Keep in mind that while similarly named elements appear in both the NASA Two-Line and TBUS bulletins, the values are NOT interchangeable between systems to compute satellite tracks. Table 1-4 is an example of a NASA Two-line bulletin and table 1-5 is a description of the information.

NAVSPASURCEN ORBITAL DATA

The Naval Space Surveillance Center (NAVSPASURCEN) in Dahlgren, Virginia, tracks all U.S. and foreign-operated satellites and space debris. Navy and Marine Corps satellite-receiver system users may request message support for satellite tracking information. The AN/SMQ-11 contains software designed to use and interpet separate messages of data known as *Satellite Equator Crossings.* TESS uses a product known as *C-Element Orbital Data* to calculate orbits for the AN/SMQ-11.

A Satellite Equator Crossings message contains information similar to TBUS Part I. The AN/SMQ-11 needs to be updated frequently (about every 2 days) by using the information from this product. The message contains information on all U.S. and foreign-operated environmental satellites. Table 1-6 contains a portion of a Satellite Equator Crossings message with explanations of the elements required to update the AN/SMQ-11. The underlined elements are required input.

C-Element orbital data also contains information similar to Part IV of the TBUS bulletin. See table 1-7 for an example of a typical message containing C-element orbital data and table 1-8 for an explanation of the data. In the C-element orbital data message, each line of data is repeated three times. This is done so that

Table 1-4.—Sample NASA Two-line bulletin

```
NOAA 14
1 23455U 94089A 95222.82483495 .00000053 00000-0 53646-4 0 2755
2 23455 98.9047 164.9161 0010620 42.0812 318.1174 14.11526152 31526
```

Table 1-5.—Explanation of NASA Two-line bulletin elements

NOAA-14	Satellite name
1 23455U	1- Message line 1 23455- Satellite number 23455
94089A	94- Launch year 1994 089- Launch number 89 A- Launch piece A (not in multiple pieces)
95222.82483495	95- Epoch year 1995 222.82483495- Julian day 222 and fraction
.00000053	First time derivative of the mean motion (decay rate, plus sign implied)
00000-0	Second time derivative of the mean motion
53646-4	BSTAR drag term
0	Ephemeris type (zero)
2755	Element number 275, 5- Check sum
2 23455	2- Message line 2 223455- Satellite number 23455 (repeated)
98.9047	Orbit inclination 98.9047 degrees
164.9161	Right ascension of ascending node 164.9161 degrees
0010620	Eccentricity .0010620
42.0812	Argument of perigee 042.0812 degrees
318.1174	Mean anomaly 318.1174 degrees
14.11526152	Mean motion 14.11526152 revolutions per day
31526	3152- Satellite revolution 3152 at epoch 6- Check sum

Table 1-6.—A Portion of a NAVSPASURCEN Satellite Equator Crossings Message

```
FM NAVSPASURCEN DATA DAHLGREN VA
TO USS NOBODY
BT
UNCLAS //N03840//
SUBJ: SATELLITE EQUATOR CROSSINGS
ASC EQUATOR CROSSINGS FOR SATELLITE 16969 NOAA 10
ALT/KM  INCLINATION  NODAL PERIOD  NODAL INCR
   810  98.59575       101.2068        25.30

HRMNSE  LONG    DAY/YR  REV
011022   86.6W  169/97  19473→Orbit # of first crossing
025134  111.9W     ↳Consecutive day (Julian day) and year of first orbit
043246  137.2W
061359  162.5W
071511  172.2E
            →Ascending node equator crossing longitude
      →Ascending node equator crossing time (hours, minutes, seconds UCT)
```

(Message continues with equator crossing times (UCT) and east/west longitudes for several crossings, and then provides similar information for many other satellites)

Table 1-7.—C–Element Orbital Data Message

```
ZNR UUUU
R 041727Z MAR 97
FM NAVSPASURCEN DAHLGREN VA
TO XXXXXX
BT
UNCLAS //N03840//
16969.2907047.8352017.99938.0013459.5727927.8105893.2739137970307
16969.2907047.8352017.99938.0013459.5727927.8105893.2739137970307
16969.2907047.8352017.99938.0013459.5727927.8105893.2739137970307
19531.0665307.8281567.99929.0011969.5853780.5828128.2749230970307
19531.0665307.8281567.99929.0011969.5853780.5828128.2749230970307
19531.0665307.8281567.99929.0011969.5853780.5828128.2749230970307
21263.3456862.8339169.00000.0068626.5838341.3961844.2740511970306
21263.3456862.8339169.00000.0068626.5838341.3961844.2740511970306
21263.3456862.8339169.00000.0068626.5838341.3961844.2740511970306
BT
```

any "hits" on the signal during transmission may be detected and corrected by the user. Because of this format, the message is sometimes called *"3-line Charlie data."* The periods separate individual data elements, and in most cases, indicate a decimal point.

Be aware that the NAVSPASUR-assigned identification numbers do not correspond to either U.S. satellite numbers or to the international satellite identification. The Satellite Equator Crossings message provides both NAVSPASURCEN's satellite number and the satellite name, such as 21263, NOAA 12.

REVIEW QUESTIONS

Q42. What is the purpose of ephemeris data?

Q43. What are the most common methods of obtaining TBUS data?

Q44. What information is contained in Part I of the TBUS message?

Q45. What general information is contained in Part IV of a TBUS message?

Q46. What is the second element of a NASA Two-line message?

Table 1-8—Format of C-Element Data

C-ELEMENT DATA LINE

AAAAA BBBBBBB CCCCCCC DDDDD EEEEEEE FFFFFFF GGGGGGG HHHHHHHIIIIII
16969.2907047.8352017.99938.0013459.5727927.8105893.2739137970307

ELEMENT INTERPRETATION

AAAAA	=	NAVSPASURCEN Satellite number	(example: #16969)
BBBBBBB	=	Raw mean anomaly (7 decimal places)	(example: 0.2907047)
CCCCCCC	=	Raw mean motion (7 decimal places)	(example: 0.8352017
DDDDD	=	Raw orbital decay (5 decimal places)	(example: 0.99938)
EEEEEEE	=	Orbital eccentricity (7 decimal places)	(example: 0.0013459)
FFFFFFF	=	Raw perigee (7 decimal places)	(example: 0.5727927)
GGGGGGG	=	Raw ascension (7 decimal places)	(example: 0.8105893)
HHHHHHH	=	Raw inclination (7 decimal places)	(example: 0.2739137)
IIIIII	=	Epoch date in form YYMMDD (year, month, day)	(example: 97/03/07)

Q47. How often should equator-crossings ephemeris data be updated for the AN/SMQ-11?

Q48. Where does ephemeris data for DMSP satellites originate?

SUMMARY

In this chapter we have discussed the various applications of satellite data and some basic terms used to discuss satellite orbits and satellite imagery acquisition. We have identified several types of environmental satellites and explained the advantages and disadvantages of each. We have also discussed the use of various types of satellite imagery, and also introduced you to some basic imagery enhancement techniques. We described several methods used to acquire satellite imagery, and the basic equipment used at Navy and Marine Corps shore stations and aboard ships to receive imagery. We also discussed some of the bulletins that provide the orbital data required as input for satellite receiver-processors.

ANSWERS TO REVIEW QUESTIONS

A1. *Zero degrees (0°).*

A2. *Geostationary, earth-synchronous, or geosynchronous.*

A3. *Ascending-node.*

A4. *The satellite's orbit is synchronized with the movement of the sun across the earth's surface.*

A5. *0200 local.*

A6. *Major changes in a satellite's apogee and perigee positions are caused by the shape of the earth, and the gravitational pull of the earth, sun, and moon.*

A7. *Atmospheric sounders provide vertical temperature and moisture profiles, and atmospheric stability data.*

A8. *Geostationary satellites are ideal for making large-scale, frequent observations over a fixed geographical area*

A9. *GOES East.*

A10. *Polar-orbiting.*

A11. *Because of their relatively low-altitude orbits, polar-orbiting satellites provide higher resolution data than geostationary satellites. They also provide imagery for the high-latitude and polar regions.*

A12. *2700 km (1500 nmi).*

A13. *Fleet Numerical Meteorology and Oceanography Center (FNMOC).*

A14. *METEOSAT*

A15. *A radiometer.*

A16. *The sensor with 1 kilometer spatial resolution.*

A17. *The cold object.*

A18. *Longwave radiation.*

A19. *Red.*

A20. *Sand.*

A21. *Infrared imagery is available day and night. It is also an excellent tool for oceanographic analysis and is also helpful for identtfiing upper-level features.*

A22. *White.*

A23. *Relatively light gray shades.*

A24. *Water vapor imagery produces better definition of the moisture distribution and circulation patterns in the upper atmosphere.*

A25. *An enhanced satellite image provides better definition, which allows the user to view specific details.*

A26. Too much definition in an enhancement curve may make the the imagery difficult to interpret.

A27. A split enhancement curve.

A28. Sector identification information.

A29. 10°C.

A30. U.S. Coast Guard.

A31. DMSP.

A32. The GOES-TAP system.

A33. A satellite looper stores and displays a series of satellite images over the same area, which, in turn, shows the movement of cloud and weather systems.

A34. APT satellite transmissions provide real-time data and are relatively inexpensive to obtain.

A35. APT is at I-kilometer resolution and HRPT is at 1-kilometer resolution.

A36. Low- and high-resolution imagery meteorological and oceanographic charts, TBUS data, and operational messages.

A37. The Internet.

A38. AUTODIN message.

A39. DMSP, APT and HRPT (NOAA), and WEFAX.

A40. Both APT (NOAA) and WEFAX

A41. The WEFAX antenna.

A42. Ephemeris data allows satellite receiver systems to predict when and where satellites will be at any given moment. It also allows receiver systems to earth-locate satellites, which aids in gridding.

A43. TBUS data can be obtained via AUTODIN message, AWN the fleet multichannel broadcast, or via the Internet.

A44. Part I of the TBUS message contains equator-crossing reference information.

A45. Part IV of the TBUS message contains high-precision orbital calculation elements, transmission frequencies, and remarks.

A46. The launch year, launch number, and number of launch pieces.

A47. About every 2 days.

A48. Naval Space Surveillance Center, Dalhgren, Virginia